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**Bilingualism meets autism:  
An investigation of executive functions profiles in  
English-Arabic children.**

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# Abstract

Autism is described as a lifelong neurodevelopmental spectrum condition, with each individual varying in their abilities across social and cognitive domains. The current prevalence estimates range between 1/100 and 1/132 worldwide. Autism is characterized by a complex collection of manifestations, with repetitive behaviours, social communication difficulties, and sensory hypersensitivity and hyposensitivity.

There is evidence to suggest that certain executive function (EF) skills (a group of important thinking skills that allow individuals to set and complete goals) are impaired in autistic children. These include interference control (the ability to resist distracting information), flexible switching (the ability to switch between thoughts and adapt behaviour according to a changing environment) and sustained attention (the ability to focus over a period of time). Furthermore, impairments in these EF domains have been evidenced to underlie some of the key characteristics of autism and negatively impact quality of life.

There is also evidence to suggest that knowledge of two languages (i.e., bilingualism; a skill shared by more than half of the world's population, comprising an extensive spectrum of language experiences and markers) has the potential to ameliorate these EF domains. This evidence is surrounded by debate, however, with evidence for and against a bilingual advantage. Nevertheless, bilingual disadvantages in EF domains are rarely, if ever, in evidence. Despite this, there are parent and practitioner concerns with respect to raising autistic children speaking more than one language. This raises the question: what kind of impact does bilingualism have on the EF abilities of autistic children? Could bilingualism mitigate potential EF difficulties in autistic children? Well, only a handful of studies worldwide have explored this question, all of which strongly support the idea that bilingualism is not harmful to autistic children's EF development, and may even confer some advantages. Nevertheless, our understanding of the EF profiles of bilingual autistic children remains very limited.

Given the rising diagnostic rates of autism and increases in the worldwide bilingual population, it is imperative to chart the effects of bilingualism on autism, especially in a domain evidenced to impact quality of life like EF. This doctoral research explores the effects of bilingualism on a group of EF skills selected based on their theoretical relevance to bilingualism (i.e., the Adaptive Control Hypothesis) and autism (the Executive Dysfunction Theory). All data were collected in the United Arab Emirates, a country that offers a

predominantly dual-language switching environment (i.e., using two languages in the same context), which is also of theoretical relevance to bilingualism.

Using directly-assessed, experimental measures of EF, findings from the first investigation (Chapter 3) with 93 participants (autistic and typically developing), revealed an advantage for bilingual autistic children on one outcome measure of sustained attention and equivalent performance to monolingual autistic children on all other EF outcome measures. The findings from this investigation, however, reflect EF performance using laboratory-type tasks, assessed at one point in time. This is at best, a partial picture of EF, bilingualism and autism.

Therefore, I then asked, what is the impact of bilingualism on EF if the measures deployed capture a wider time span and everyday types of situations? To address this knowledge gap, I launched the second investigation (Chapter 4) with 80 participants (autistic and typically developing) using informant-report measures of EF, capturing both parent and teacher perspectives on children's abilities. The first key finding is that parent-reported EF revealed an advantage for bilingual autistic children on all EF domains, relative to monolingual autistic peers. The second key finding is that second language proficiency predicted parent-reported sustained attention, and second language current exposure predicted parent-reported interference control. The third key finding is that poorer parent-reported EF abilities were associated with more clinically significant features of autism.

Given the known heterogeneity between autistic children, my third and final investigation (Chapter 5) went on to examine variability in my data in more detail, using a multiple case series approach to analyse EF data from 27 autistic participants. The first key finding was that the individual experience of autism seemed to shape EF capabilities. To illustrate, in contrast to group-level findings (Chapters 3 and 4) which framed autistic group performance as 'impaired', a multiple case series analysis showed that the majority of autistic participants performed equivalently to typically developing peers. The second key finding is that I found no support for 'spiky' autistic EF profiles (i.e., one that has a mix of enhanced, impaired, and average performance). The third key finding was that more strengths were revealed on directly-assessed EF than parent-reported EF, which was, in turn, more positive than teacher-reported EF.

To my knowledge, this is the first investigation at this interface to use a multidimensional EF approach – EF was assessed via a combination of direct and informant-based (parent and teacher reports) measures – and to employ mixed analytic methods (i.e., group and multiple case series analysis). Further new contributions come from the inclusion

of sustained attention as a relevant domain of interest. Additionally, this work contributes to the diversification of autism research samples beyond WEIRD (western, educated, industrial, rich, and democratic) samples. Finally, this work contributes new findings from the targeted investigation of the Adaptive Control Hypothesis theoretical model in a non-typical population. In the final chapter (Chapter 6), the overall findings of the study are discussed, to draw conclusions, identify evidence-based implications for families, practitioners, researchers, and chart new areas of bilingualism research in childhood autism.

# Lay Summary

Autism is a lifelong neurodevelopmental spectrum condition, with individual social and cognitive abilities ranging from intact to impaired. It is marked by repetitive behaviours, social communication difficulties, and sensory hypersensitivity and hyposensitivity.

There is some evidence that executive functions (EFs) (a group of important thinking skills that allow individuals to set and complete goals) are vulnerable in autistic children. Some of these include interference control (the ability to resist distracting information), flexible switching (the ability to switch between thoughts and adapt behaviour according to a changing environment) and sustained attention (the ability to focus over a period of time). Moreover, deficits in these domains have been linked to key features of autism, and have been shown to negatively impact quality of life. There is also evidence that being bilingual (a skill common to more than half of the world's population) has the potential to improve these EF abilities. While there is support for and against a bilingual advantage, there is more established consensus that bilingualism rarely, if ever, results in EF disadvantages.

Given the rising diagnostic rates of autism and increases in the worldwide bilingual population, the over-arching goal of this thesis is to investigate the impact of bilingualism on the EF abilities (selected based on their theoretical relevance to bilingualism and autism) of English-Arabic autistic children. This is especially relevant as there are worldwide concerns surrounding raising an autistic child bilingually, and only a handful of studies published to date that can provide evidence on the matter.

I report on three investigations at the interface of bilingualism, autism, and EF. Using directly-observed experimental EF measures (Chapter 3), I found preliminary evidence that bilingualism might mitigate difficulties in the sustained attention domain for autistic children. I carried out a second investigation (Chapter 4) using informant-report measures that captures both parent and teacher views on children's EF abilities, and found widespread EF advantages for autistic bilinguals (on parent-report measures only).

The results of these two analyses (Chapters 3 and 4) revealed some commonalities. First, being autistic and bilingual did not result in any EF disadvantages, relative to monolingual autistic peers. Second, as a group, autistic children exhibited significantly poorer EF abilities relative to TD peers, on most EF outcome variables. Therefore, I launched my third and final investigation (Chapter 5) to examine variability in my autistic EF data, given that autism is a heterogenous condition. A key finding of this chapter was that the

individual experience of autism seemed to shape EF capabilities. On a group-level, autistic participants seem impaired in their EF abilities, but when analyzed on an individual level, the majority of autistic participants exhibited intact EF abilities. While there was variability in the autistic group, the majority of the sample did not have spiky EF profiles (i.e., one that has a mix of enhanced, impaired, and average performance). A key finding from the thesis as a whole, is that informant-report measures captured widespread bilingualism advantages but direct assessment captures intra-individual variability more successfully.

To my knowledge, this is the first investigation at this interface to use a multidimensional EF approach – EF was assessed via a combination of direct and informant-based (parent and teacher reports) measures – and to employ mixed analytic methods (i.e., group and multiple case series analysis). Additionally, this work contributes to the diversification of autism research samples beyond WEIRD (western, educated, industrial, rich, and democratic) samples. Finally, this work contributes new findings from the targeted investigation of the Adaptive Control Hypothesis theoretical model in an autistic population.

# Declarations

I declare that this thesis was composed by myself, and, except where stated otherwise, is entirely my own work. The research presented hereafter has not been submitted for any other degree or professional qualification.

This thesis includes two articles submitted for publication:

Chapter 2: **Sharaan, S.**, Fletcher-Watson, S., & MacPherson, S.E. (2020). The Impact of Bilingualism on the Executive Functions of Autistic Children: A Study of English-Arabic Children. (*Autism Research*).

Chapter 3: **Sharaan, S.**, MacPherson, S.E., Fletcher-Watson, S. (2021). The Impact of Bilingualism on Everyday Executive Functions of English-Arabic Autistic Children: Through a Parent-Teacher Lens. (*Journal of Autism and Developmental Disorders*).

Preliminary findings from this dissertation were presented at the following conferences:

1. International Society for Autism Research – INSAR. Virtual, United States, 2020.
2. The Language Event (a branch of the Polyglot Conference). Edinburgh, United Kingdom, 2020.
3. Bilingualism Matters Research Symposium – BMRS. Edinburgh, United Kingdom, 2019.
4. International Symposium on Bilingualism – ISB 12. Edmonton, Canada, 2019.

Shereen Sharaan

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On September 2016, I undertook a life-changing journey from the Emirates to Scotland, to pursue my PhD at the University of Edinburgh. It is now September 2020. As I conclude this 4-year journey of a lifetime and seek new commitments, it is appropriate to reflect and comment on my feelings.

This PhD was a path to learning and unlearning. While I am grateful for all that I have learnt, on personal and professional grounds, I am especially grateful for all that I have unlearned – about autism. I came into this PhD with years of first-hand volunteer experiences with autistic children, under my belt. I also have an autistic sibling. So, I felt like I was approaching familiar territory with respect to the autism focus of my PhD. What I ended up discovering along the way (through several participatory autism initiatives: workshops, courses, conferences, talks, research collaborations, etc. - many of which were under the excellent leadership of Dr. Sue Fletcher-Watson), was that I had been looking at autism, my whole life, through a neuronormative lens. This was a devastating realization at first. However, watching my parents, friends, and members of my community (especially in the United Arab Emirates where I was born, raised, and currently reside) unlearn too, as a result of my committed efforts to disseminate lived experiences of autistic people and neurodiversity research insights...has been invaluable. The unique insights I acquired by being part of a leading autism research lab that facilitates meaningful participatory research, have allowed me to significantly grow in the areas of autism awareness, autism acceptance, autism appreciation, and autism empowerment – and subsequently, help others grow too. That has truly been the most rewarding and life-changing experience of my PhD journey...closely followed by the creation of this thesis.

Initially, an endless tunnel seemed to lie ahead. In that tunnel, I battled with some very high personal and professional lows. Thankfully, I had access to some pretty talented, committed, learned individuals, who made eased my way through and helped me get out safely. First, I want to profoundly thank all the parents, teachers and children who took part in my research – as well as the UAE bodies that granted me access to them; without you all, I would not have a thesis. Second, I give thanks and gratitude to Dr. Sue Fletcher-Watson, for her

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# Chapter 1: Introduction

The current work explores the impact of bilingualism on the executive functions profiles of autistic children, positioning itself at the interface of three fields: autism, executive functions, and bilingualism. In this introductory chapter, I review the relevant literature within each field, highlighting the overlap across the three fields, and finally, setting the scene for my doctoral research.

## 1. Autism

### A. Defining autism

Autism, otherwise known as autism spectrum (ASCs), is described as a lifelong neurodevelopmental spectrum condition with each individual varying in their abilities (strengths and difficulties) across social and cognitive domains. This combination of strengths and difficulties can vary over time. What characterizes autism is a complex collection of manifestations, namely, repetitive behaviors, social communication difficulties, and sensory hypersensitivity and hyposensitivity (American Psychiatric Association, 2013). While the etiology of autism remains unknown, a combination of genetic and environmental factors have been hypothesized to play a role in its development (Chaste & Leboyer, 2012; Sylvie et al., 2014). Autism is often accompanied by single or multiple co-occurring conditions that may develop during different life stages (Doshi-Velez, Ge, & Kohane, 2014; Lai et al., 2019). This can include intellectual disability, language delay, medical conditions (e.g., epilepsy, gastrointestinal problems) and psychiatric conditions (e.g., depression, attention deficit and hyperactivity disorder). The current worldwide prevalence is estimated to be 1/132 (Baxter et al., 2015), with males being more frequently diagnosed than females (Loomes, Hull, & Mandy, 2017).

A number of theories have been proposed to explain the key characteristics of autism, including the ‘theory of mind deficit’ theory, which states that autistic individuals tend to be compromised in the ability to mentalize or infer the mental states of others (Baron-Cohen et al., 1985); the ‘weak central coherence’ theory, which states that autistic individuals tend to process parts or detailed information of objects or situations rather than their global meaning (Frith, 1989); and the ‘executive dysfunction’ theory, which states that deficits in EF underlie the key features of autism (Hill, 2004). It is imperative to note that no single theory has been

able to account for the diversity of individual profiles and affected domains linked to autism (Happé, Ronald & Plomin, 2006).

## **B. Autism and language**

Prior to discussing executive functions and bilingualism in autism, it is fitting to briefly discuss language abilities in autism. A wide range of language profiles exist within the autistic population. Profiles range from minimally verbal (an estimated 25% to 35% of autistic children) to relatively unimpaired or even enhanced language abilities (Hyltenstam, 2016). Language acquisition in autism is marked by significant delays, with expressive language first produced at a mean age of 38 months, relative to 8 to 14 months in typically developing (TD) children. As a matter of fact, one of the primary concerns communicated by parents of autistic children relates to language delays in early life (Mitchell et al., 2006; Tager-Flusberg, 2000).

Pragmatic abilities, a hallmark feature of autism, have received special attention in investigations of autistic language abilities. Evidence suggests that, regardless of age, autistic individuals display persevering difficulties in pragmatics (Tager-Flusberg, Paul, & Lord, 2005). Difficulties in both staying on topic (Nadig, Lee, Singh, Bosshart, & Ozonoff, 2010) and interpreting language beyond its literal sense (Philofsky, Fidler, & Hepburn, 2007) are some of the main deficits associated with the social application of language in autistic individuals.

Researchers have also reported on common speech impairments in autism: echolalia (repetition of another person's spoken words with similar intonation) (Tager-Flusberg, 2000), pronoun reversal (referral to oneself as "he", "she", or "you" – instead of "I") (Frith & Happé, 1994), a perseverative focus on idiosyncratic language (the use / over-use of words / expressions to refer to something unrelated) (Volden & Lord, 1991), and pedantic speech (for example, an excessively formal speaking style, very precise articulation, and increased fixation on details) (Ghaziuddin & Gerstein, 1996). It is important to note, however, that impairments in language capabilities are recognizably different from general non-verbal cognitive capabilities (Silleresi et al., 2020). In that study, language impairments in a group of 51 autistic children (14 of which were classified as bilingual) were detected irrespective of non-verbal intelligence levels.

Finally, researchers have also reported on some strengths in the language profile of autistic individuals. In the lexical domain, evidence suggests that vocabulary is a domain

where autistic children generally exhibit strengths, compared to other linguistic domains (Tager-Flusberg, 2000). Nevertheless, the vocabulary profiles are characterized by heterogeneity, a common finding in the autism literature (Anderson et al., 2007). While some children amass a narrow range of words, others acquire sizeable vocabularies (in some instances, associated to their specific interests) (Frith & Happé, 1994). In the semantic domain, autistic children have been reported to classify objects into distinct perceptual dimensions (Ungerer & Sigman, 1987) and map words to novel items (Bani Hani, Gonzalez-Barrero, & Nadig, 2013). In summary, while language delays, pragmatic difficulties, and lexical strengths are reported throughout the literature, language in autism is marked by heterogeneous profiles.

### **C. Autism and executive functions**

Executive functions (EFs) refer to a broad range of higher-order thinking skills that include, but not limited to, sustained attention (the ability to focus over a period of time), interference control (the ability to resist distracting information), flexible switching (the ability to switch between thoughts and adapt behavior according to a changing environment), and working memory (the ability to use short-term memory) (see McCloskey et al. (2009) for a review of EF definitions). The fact that you are able to read and retain some content from this thesis while ignoring e-mail alerts, text messages, and disruptions from family members or pets, is related to your ability to exercise the aforementioned EF domains. A range of outcomes pertaining to educational (Allan, Hume, Allan, Farrington, & Lonigan, 2014) and social (Hughes, White, Sharpen, & Dunn, 2000) contexts have been linked to EF abilities. Furthermore, such abilities have been evidenced to broadly influence quality of life (Tangney, Baumeister, & Boone, 2004).

A range of neurodevelopmental conditions have been linked to impairments in EFs, including attention deficit and hyperactivity disorder (Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2004), schizophrenia (Velligan & Bow-Thomas, 1999), obsessive-compulsive disorder (Olley, Malhi, & Sachdev, 2007), and autism spectrum conditions (Hill, 2004). Strong EF skills have been proposed to be a protective factor against such developmental conditions and disorders (Johnson, 2012). Some have proposed that the theory of executive dysfunction provides an explanatory theoretical model for autism (Hill, 2004), with particular links drawn to non-social aspects of autism (i.e., repetitive and restricted behaviors). However, key limitations of the executive function theory include: (a) the uncertainty

surrounding the specific EF skills impacted in autism, (b) lack of specificity when applied to autism, given that other neurodevelopmental conditions have also been linked to EF deficits, and (c) the presence of heterogeneous EF profiles within autism.

The next section reviews some evidence on the EF profiles of cognitively-abled autistic children, adolescents and young adults, with a specific focus on the following EF domains: interference control, working memory, flexible switching and sustained attention. These domains were selected as they overlap the EF domains highlighted in the bilingualism literature and correspond with the predictions of the guiding theoretical framework of this work.

*Interference control.* Interference control refers to the competence with which one can disregard impertinent information while processing pertinent stimuli. A well-established body of literature presents evidence for and against the hypothesis that autistic individuals are impaired in the interference control domain. While some studies demonstrate autistic deficits in interference control (Adams & Jarrold, 2012; Christ, Kester, Bodner, & Miles, 2011; Larson, South, Clayson, & Clawson, 2012; Yoran-Hegesh, Kertzman, Vishne, Weizman, & Kotler, 2009), other studies report equivalent performance between autistic and TD groups (Geurts, Luman, & van Meel, 2008; Kiliñçaslan, Motavalli Mukaddes, Sözen Küçükyazıcı, & Gürvit, 2010; Schmitz et al., 2006). In an attempt to gain a more thorough perspective of interference control in autism, a meta-analysis was conducted by Geurts, Bergh, and Ruzzano (2014) using 41 studies (a total of 1,091 participants with a mean age of 14 years). The authors revealed interference control deficits in autism in comparison to TD peers (effect size 0.31). They also discussed a combination of sample and task characteristics that could explain the heterogeneity they found across the selected studies.

The first factor relates to intellectual functioning. In contrast to age, IQ was reported as a relevant moderator for interference control, suggesting that an increase in IQ was associated with a decrease in the detected effect size for interference control. The authors suggested it could explain some of the disparities in findings between studies. For example, in the Christ et al. (2011) study, autistic participants had slightly lower IQ scores than their TD peers. These differences in intellectual functioning may have confounded the results which indicated autistic performance deficits in relation to TD peers. Another study that supports this interpretation is that by Sanderson and Allen (2012) which reported no autistic impairments in interference control for IQ-matched participants. The second factor relates to autism sub-types. The majority of studies made no distinction between the different subtypes of autism (i.e., autism, pervasive developmental disorders not otherwise specified) which

could have contributed to some variability. They also varied in the type of tools used to assess profiles. The third factor relates to task characteristics; the tasks deployed in these studies widely vary on a number of factors, including stimulus presentation duration, number of trials, and the amount of conflict on a task.

In summary, it is unsurprising that the literature on interference control is marked by heterogeneity, given the variable factors at hand. It seems that both sample and task characteristics contribute relatively equally to the inconsistencies. The state of the literature on interference control in autism illustrates the need for further research that targets the exploration of specific factors which impact performance.

*Working memory.* Working memory refers to the ability to remember certain short term memories required to complete a function or daily task. Studies investigating working memory in childhood autism have yielded inconsistent findings. While some studies demonstrate autistic deficits in working memory (Gomarus et al., 2009; Steele et al., 2007; Yerys et al., 2011), other studies report intact performance for autistic individuals (Faja & Dawson, 2014; Guerts et al., 2004; Ozonoff et al., 2001). In efforts to gain a more comprehensive stance on working memory in autism, a meta-analysis was first conducted by Wang et al. (2017) using 28 studies (a total of 1,694 participants with a mean age of 22 years). Another meta-analysis conducted by Habib et al. (2019) adopted a more extensive search and more stringent inclusion criteria, using 34 studies (a total of 1,874 participants with a mean age of 20 years). Both meta-analyses reported significant impairments (effect sizes 0.61 and 0.70 respectively) in autistic individuals, across diverse measures and outcome variables of working memory.

This suggests that autistic impairments in working memory are independent of task modalities. This is unlikely to be due to publication bias, as the latter meta-analysis suggests that studies are equally likely to be published irrespective of statistical significance. Furthermore, both meta-analyses report that sample characteristics such as IQ and age do not account for any significant variation between the studies. However, Poirier et al. (2011) point out that when participants are matched on verbal IQ, assessed by the Weschsler Intelligence Scale, differences between groups on tasks of working memory might be underrated as the measure on which groups are matched presents a sub-test of working memory. Therefore, groups might be matched on the dimension under investigation and of interest (i.e., working memory); a critical methodological aspect for future research to take into account.

While the results of meta-analyses suggest autistic impairment in working memory, it is worth commenting on some limitations. First, the majority of studies included in the meta-

analyses had relatively small sample sizes. This could result in underpowered studies which increases the likelihood that a statistically significant finding represents a false-positive result (Vankov et al., 2014). Second, the majority of studies did not control for or report any co-morbidities in their autistic participants. Therefore, it is possible that the observed working memory deficits might be attributable to conditions other than, or in combination with, autism. Third, differences in the types of comparison participants could have resulted in discrepant findings. For instance, evidence of unimpaired working memory is typically located in studies that compared autistic individuals to individuals with intellectual disabilities, whereas evidence of impaired working memory is typically detected in studies that compared autistic individuals to TD peers (Russo et al., 2007).

*Flexible switching.* Flexible switching refers to the ability to switch between thoughts and adapt behavior according to a changing environment. Just like the previous two EF domains, discordant findings exist across investigations of flexible switching in autism. While some studies report autistic impairments in flexible switching relative to TD peers (Liss et al., 2001; Yerys et al., 2009), other studies report comparable performance between autistic and TD groups (Poljac et al., 2010; Stahl & Pry, 2002). A review by Russo et al. (2007) that primarily focused on children suggests that deficits in flexible switching exist even at younger developmental levels (early childhood). The review, however, was narrative in nature and did not reveal the magnitude of effect across the selected studies. Using meta-analytic methodology, Lai et al. (2017) revealed cognitive flexibility impairments (effect size 0.59) for autistic participants made up of children and adolescents (using 98 studies and a total of 5,991 participants with a mean age of 10 years). Considerable variability of effect sizes was noted, with the least deficit recorded by the intra-extra dimensional set shift task of the CANTAB battery. Guerts et al. (2009) suggested, however, that failure to complete the task's stages can be attributed to deficits in sustained attention, rather than flexible switching. This is because flexibility switching only takes place in the final section of the task, rather than throughout the task.

A number of key factors have been highlighted in relation to the evidence-base on flexible switching functioning in autism. First, the use of measures that tap into multiple EF components to assess flexible switching can complicate the disentanglement of effects in flexible switching. A prime example of such a measure is the Wisconsin Card Sorting Task (WCST), a test that often reveals deficits for autistic individuals. The WCST exercises several EF domains including working memory, response inhibition, and flexible switching; therefore, we are unable to attribute autistic deficits to a specific EF domain. Second, the



predictability of switches is likely to influence results, as proposed by Geurts et al. (2009). There is evidence that autistic individuals display unimpaired flexible switching when carrying out tasks with predictable switches (Stahl & Pry, 2002; Whitehouse et al., 2006). On tasks where switching occurs in a random and unforeseeable manner, however, autistic individuals display impaired flexible switching performance (Maes et al., 2011; Stoet & López, 2011).

Third, working memory has been proposed to have a potential influence on findings. Some studies report intact flexible switching performance on tasks that elicited low working memory demands for autistic participants (Schmitz et al., 2006; Stoet & López, 2011). When those demands were increased, however, the findings are mixed with some studies reporting deficits (Maes et al., 2011; Stoet & López, 2011) and others not (Poljac et al., 2010). Fourth, the explicitness of task instructions in flexible switching tasks has been highlighted in the literature; when it was minimal, autistic participants displayed impaired flexible switching performance (Van Eylen et al., 2016). Finally, choice of matching measures in the autism literature has been raised as a methodological concern, as highlighted in a study that investigated flexible switching performance in autistic children using the Dimensional Change Card Sorting Task (DCCS) (Zelazo, Jacques, Burack, & Frye, 2002). Autistic children and their TD peers showed equivalent flexible switching performance when they were subjected to individual matching on receptive vocabulary (verbal ability), but autistic children exhibited deficits when the matching was based on non-verbal IQ.

In summary, while there is significant heterogeneity in sample characteristics across studies (e.g., age, autism sub-type), task characteristics can play a key role in influencing the outcome and interpretation of studies of flexible switching in autism.

*Sustained Attention.* Sustained attention refers to the ability to focus on a task with repeated presentation over an extended period of time. Studies on sustained attention in autism remain very limited, as the literature tends to focus on other aspects of attention such as shifting attention (i.e., flexible switching reviewed earlier). There is some evidence of impaired sustained attention abilities in autistic individuals (Murphy et al., 2014). In this study, 44 autistic participants were matched on IQ and age to 46 TD participants, with a mean age of 23 years. A couple of factors have been proposed to explain this deficit. First, in their study, Garretson et al. (1990) suggested that sustained attention impairments observed in autistic individuals could be linked to their motivational framework. Therefore, it might be that lower responsiveness to the impact of positive social reinforcement underlies deficits, rather than a primary impairment in the ability to sustain attention. Second, as highlighted

earlier, the choice of comparison group can impact the EF outcome in autism. In the study by Murphy et al. (2014), autistic participants were compared to a TD group, which might explain the observed sustained attention deficits. In line with this interpretation, a study by Alloway and Lepere (2019) reported intact sustained attention abilities in autistic children (9 participants) when they were compared to age-matched dyslexic children (9 participants). Similarly, Christakou et al. (2012) indicated no impairments in sustained attention for 20 autistic adolescents, relative to 20 adolescents with ADHD.

Across four domains of EF reviewed here, we can see that autistic difficulties are commonly reported, though no literature is unequivocal on the topic of an autistic disadvantage. Variability in results between studies can be attributed to both task effects and sample-based factors (Demetriou et al., 2017). This reveals the importance of careful selection of tasks to minimize extraneous demands, and also the value of investigating further individual differences that might contribute to EF task performance, beyond those already highlighted (e.g., age, IQ). One candidate factor could be bilingual exposure.

## **2. Bilingualism**

### **A. Defining bilingualism**

Bilingualism is a skill shared by more than half of the world's population, and broadly speaking, refers to the knowledge of more than one language (Grosjean, 2010). This includes oral and sign languages, and the knowledge of both is referred to as bimodal bilingualism. Bilingualism comprises an extensive spectrum of language experiences and markers. It encompasses individuals who: (a) are exposed to two languages from birth or a very early age (i.e., simultaneous bilinguals), (b) are exposed to the second language during childhood, after the first language is somewhat established (i.e., early sequential bilinguals), (c) are exposed to the second language after childhood (i.e., late sequential bilinguals), (d) possess equal abilities in their two languages (i.e., balanced bilinguals), (e) possess unequal abilities in their two languages (i.e., unbalanced bilinguals). The presence of all these diverse bilingual profiles increases the complexity of identifying and grouping bilinguals in research settings, which in turn, contributes to the inconsistencies in the evidence-base surrounding the impact of bilingualism on executive functions (Bak, 2016; Bialystok et al., 2012; Paap et al., 2016). A number of key markers of bilingualism have been proposed to shape its influence on executive function domains, some of which are described below. Subsequently, the next section highlights their role as moderating variables typically developing EF investigations.

*Age of acquisition.* ‘Age of acquisition’ is a term used to indicate the age at which a monolingual person first began learning a second language. Researchers in the field of bilingualism often use it as a selection criteria for bilingual participants, the usual prediction being: increased impact of bilingualism on EF domains with earlier age of acquisition. Lenneberg (1967) put forth a hypothesis that emphasized a critical period in life to learn a language, extending from early childhood to puberty. In bilingualism research, the critical period hypothesis has received mixed feedback, with some disapproving of the idea that there are critical periods restricting the acquisition of language (Bialystok & Kroll, 2018) and others supporting the idea that language acquisition is dependent on such effects (Meisel, 2013). The nature, causes, and duration of the critical period hypothesis are not well understood, to date.

*Language proficiency.* Another parameter used to group bilinguals is language proficiency, ranging from basic functional knowledge of a language to an equal mastery of both languages (i.e., balanced bilingualism can refer to balanced use, balanced levels of proficiency, or both). A wide range of assessments are utilized across the literature to capture the proficiency variable, including self-ratings, parent-ratings, and direct assessments (e.g., expressive language measures).

*Language switching.* In everyday life, bilinguals often mix and switch between their languages (Heredia & Altarriba, 2001). The quantity and type of language switching is subject to certain factors, such as the interactional context or speaker. Interactional contexts range from strict use of just one language to flexible, uncontrolled use of both languages. Therefore, the interactional context can influence bilingual language control.

## **B. Bilingualism and executive functions**

Research on the cognitive effects of bilingualism has largely focused on executive functioning (see Donnelly et al. (2019) and van den Noort et al. (2019) for meta-analysis and systematic reviews). The following section reviews evidence on the EF profiles of TD bilingual children and young adults, with a specific focus on the following EF domains: interference control, working memory, flexible switching and sustained attention. These have been selected for their relevance to autism [[Section 1.1c](#)] and to one prominent theoretical account of the influence of bilingualism on executive function [[Section 1.2c](#)].

*Interference control.* The evidence regarding a bilingual advantage in interference control remains mixed. There is evidence of a bilingual advantage in interference cost for

bilingual children (e.g., Yang et al., 2011), evidence of an inconsistent bilingual advantage in interference cost in a review by Hilchey, Saint-Aubin, and Klein (2015), and evidence for a weak bilingual advantage in a meta-analysis conducted by Donnelly et al. (2019), using 80 studies and 253 comparisons of bilinguals and monolinguals. The effect size (0.11) was found to be moderated by age of acquisition but not by age or task type.

Several potential moderators have been discussed throughout the literature, in relation to interference control performance. First, a study by Iluz-Cohen and Armon-Lotem (2013) reports that the more proficient a bilingual child is in one or both languages, the better the performance on interference control. This finding is consistent with that of Tse and Altarriba (2014) who reported that interference control was predicted by bilinguals' second language proficiency. However, there is also evidence that language proficiency did not predict interference control, but rather, parent-rated response inhibition (Verhagen et al., 2019). On that note, an important distinction between 'response inhibition' and 'interference control' has been notably featured in the bilingualism literature (Bunge et al., 2002; Martin-Rhee & Bialystok, 2008). While the former requires the inhibition or suppression of actions that are inappropriate in a given context (e.g., inhibiting the habitual behavioral response of eating cake upon craving it, while on a diet), the latter requires resisting interference from distracting irrelevant information while attending to relevant information or tasks. It has been argued that the former type of inhibition does not replicate the bilingual experience; being bilingual does not involve overriding a habitual response. The latter, however, allows for the suppression of one interfering 'distractor' active language system, while speaking in another active language.

To illustrate, Martin-Rhee and Bialystok (2008) compared performance between bilingual and monolingual participants on two types of inhibition tasks. The task that exercised interference control abilities yielded a bilingual advantage, whereas the task that elicited a response inhibition condition did not. In fact, brain evidence points to two different brain activations for interference control (prefrontal activation) and response inhibition (posterior activation), and suggests that children are more capable of interference control than adults but less capable of response inhibition than adults (Bunge et al., 2002). Therefore, while the studies reviewed here focus on interference control rather than response inhibition, I point out that the type of inhibition is a key factor to take into consideration when interpreting the inconsistencies in the larger bilingualism and inhibition literature.

Another potential moderator, albeit one that has yielded mixed findings, is age of acquisition. A study by Luk et al. (2011) revealed an advantage for early bilinguals, relative

to late bilinguals, on a task of interference control. This finding was echoed in a study by Kalia et al. (2014) who reported that early bilinguals (acquired both languages before the age of 6 years) outperformed late bilinguals (acquired both languages after the age of 6) on an interference control task. In contrast to these studies which highlight interference control advantages for early bilinguals, a study by Pelham and Abrahams (2014) found equivalent interference control benefits both for early (acquired both languages before 7 years of age) and late (acquired both languages after 13 years of age) bilinguals. Others like Paap et al. (2014) reported a bilingual advantage in interference control, but the finding did not stand for early bilinguals.

Language switching is another potential moderator that has been linked to interference control performance. There is evidence of a positive relationship between interference control skills and frequent language switching abilities in early bilinguals (Verreyt, Woumans, Vandelandotte, Szmalec, & Duyck, 2016). Another study noted that it was actually the type of language switching, rather than just frequency, which predicts interference control (Hofweber, Marinis & Treffers-Daller, 2016). In this study, bilinguals who were primarily engaged in dense-language switching showed interference control advantages on a high-monitoring condition of a flanker task. In summary, interference control is often, but not always reported as enhanced (effect sizes are relatively small) by bilingual exposure. Language characteristics such as early bilingualism, language proficiency and language switching have been identified as some of the key moderators with potential to exert an influence on interference control outcomes.

*Working memory.* There are two opposing views regarding the relationship between bilingualism and working memory capacity in the literature. The first view suggests that managing multiple languages at the same time could place significant demands on working memory, and consequently, obstruct effective processing in working memory due to cognitive overload (Sweller & Chandler, 1994; van Merriënboer & Sweller, 2005). In contrast, the second view suggests that this exact process of managing multiple languages involves processes of higher-order executive control (Bialystok et al., 2012), many of which are positively related to working memory (Engle, 2002; Rosen & Engle, 1997). While some research supports a bilingual advantage in working memory capacity (Morales et al., 2012; Soliman, 2014), other studies did not find a bilingual advantage (Namazi & Thordardottir, 2010; Ratiu & Azuma, 2014).

Some studies propose age as a moderating variable (Bialystok, Martin, & Viswanathan, 2005). A recent meta-analysis reported a significant small to medium effect

size in favor of a bilingual advantage for working memory, with the greatest group differences in working memory performance located in children (Grundy & Timmer, 2016). The findings support the hypothesis that children would demonstrate the greatest effects due to the cognitive demands incurred by learning a new language, and their brain plasticity compared to other age groups (Johnston, 2009). Another variable examined in the literature is the language in which the tasks are performed. The meta-analysis revealed that bilinguals outperformed monolinguals when performing the task in their first language, but not their second language (Grundy & Timmer, 2016). The findings are in line with studies demonstrating slower lexical retrieval for second language compared to first language production (for a review, see Goldrick et al., 2014).

Working memory performance might also vary depending on the task type. Studies report bilingual disadvantages on tasks that require verbal processing (Bialystok et al., 2012; Fernandes et al., 2007; Luk & Bialystok, 2012). The recent meta-analysis by Grundy and Timmer (2016), however, reported that task type did not moderate the relationship between bilingual status and working memory performance, suggesting that bilinguals generally perform better than monolinguals on tasks of span regardless of the verbal nature of the task. In summary, working memory is often, but not always reported as enhanced by bilingual exposure. Sample (e.g., age) and language characteristics (e.g. language chosen) are some of the key contributors to the inconsistencies surrounding the working memory evidence-base in bilinguals.

*Flexible switching.* A number of studies have shown a bilingual advantage for children on flexible switching, using the DCCS task in particular (Barac & Bialystok, 2012; Bialystok & Martin, 2004; Bialystok & Shapero, 2005; Carlson & Meltzoff, 2008). The task requires participants to sort by two independent dimensions; one dimension (i.e., sorting by color) in the pre-switch phase and another dimension (i.e., sorting by shape) in the post-switch phase. On the other hand, Paap et al. (2016) systematically reviewed a large number of studies only to conclude there may be no differences between bilinguals and monolinguals in flexible switching ability. A number of factors have been discussed in the literature, in relation to the flexible switching evidence-base.

A key factor relates to the unpredictability of switching on a task. Little is known about this in children, but in parallel literature with adults, Van Asselen and Ridderinkhof (2000) revealed poorer flexible switching performance when task switches were unpredictable. Kray et al. (2002) also lend support to this finding in their sample of younger and older adults. Another key factor in the literature is language switching. Findings on this

front is mixed; while some studies suggest that frequent language switching is a significant predictor of flexible switching performance (Soveri, Rodriguez-Fornells, & Laine, 2011; Prior & Gollan, 2011), other studies with larger samples did not (Paap, Johnson, & Sawi, 2015; Paap et al., 2016). In addition to the frequency of language switching, the type of language switching has also been explored in relation to flexible switching outcomes. Hartanto and Yang (2016) revealed that bilinguals in a dual-language interactional context had a flexible switching advantage compared to bilinguals in a single-language context.

Language proficiency has also been linked to flexible switching outcomes. A study by Iluz-Cohen and Armon-Lotem (2013) reported an advantage for bilinguals with high proficiency in their second language, relative to low proficiency bilinguals, on flexible switching outcomes. This finding was supported by Kang and Lust (2017) who found flexible switching to be influenced by bilingual children's language proficiency. In summary, flexible switching is often, but not always reported as enhanced by the bilingual experience. A combination of task characteristics (e.g., task predictability) and language characteristics (e.g., language proficiency and language switching) have been highlighted as potential moderators of flexible switching outcomes.

*Sustained Attention.* In the bilingualism literature, sustained attention has received very little scientific attention. When attention is addressed in the literature, it is mostly in the context of 'attentional control' which refers to inhibitory and / or switching abilities, rather than the ability to sustain attention. Studies that have investigated sustained attention as an independent EF domain have revealed contrasting findings. Krizman et al. (2012) examined sustained attention abilities in 48 adolescents using a continuous performance test and reported an advantage for bilinguals. More recently, however, a study by Boerma, Leseman, Wijman, and Blom (2017) examined sustained attention abilities in 128 children, also using a continuous performance test, and reported equivalent performance between bilinguals and monolinguals. While both studies used early bilinguals (age of second language acquisition was prior to the age of 4), the former study had access to bilinguals with relatively balanced high proficiencies in both their languages and highly exposed to both their languages within the home environment; two language characteristics which could have impacted sustained attention favorably.

In summary, the mixed evidence-base on the effects of bilingualism on the aforementioned EF domains stems from a number of key factors, including; a lack of clarity in how EFs are defined and assessed, a lack of control over potential EF moderators, and a lack of transparency in how bilingualism is conceptualized and assessed (see Valian, (2015)

for a review). Additionally, Paap et al. (2015) note that most bilingual advantages stem from underpowered studies with low sample sizes. Using meta-analytic methodology, Lehtonen et al. (2018) add that bilingual advantages in flexible switching, working memory, and interference control disappeared following adjustment for publication bias in their examination of 152 studies. Furthermore, the issue of task impurity (Burgess, 1997) must be acknowledged. Basically, task impurity implies that the presence of multiple EF domains within a single task. Therefore, teasing out the individual contributions of each EF domain within a task can be extremely challenging. Therefore, task impurity can likely contribute to errors in measurement, noise, and complexity in assessing the EF domain under investigation.

Finally, a number of enriching and cognitive-boosting experiences can produce advantages similar to those delivered by the bilingual experience; these include musical training, video gaming, and exercise are some relevant examples (see Valian, 2015 for a focused review on children, adolescents, and young adults).

### **C. Bilingualism and executive functions: Theoretical underpinnings**

The bilingual advantage hypothesis posits that there is a bilingual advantage across linguistic and non-linguistic domains; an idea that has received support from a number of investigations (e.g., Bialystok, Craik, & Luk, 2008; Coderre & van Heuven, 2014; Marton, Goral, Campanelli, Yoon, & Obler, 2017; Stocco & Prat, 2014). Nevertheless, in line with the mixed evidence on selected EFs reviewed above, the bilingual advantage hypothesis is not universally accepted. Evidence for any given outcome is equivocal at best. Some argue that it is challenging to generalize the effects of bilingual advantages and that these effects might only appear under specific conditions. Hilchey and Klein (2011) and von Bastian, Souza, and Gade (2016) condensed the general, complex concept of ‘bilingual advantage’ to five specific hypotheses that individually attempt to pinpoint the domain-general cognitive processes improved by the bilingual experience. Each hypothesis predicts how the bilingual advantage will emerge across various general non-linguistic-type measures. Table 1 summarizes the five bilingual advantage hypotheses.

**Table 1.** Summary of five bilingual advantage hypotheses (Vinerte and Sabourin (2019)).

Hypothesis	Predictions	Mechanisms tested	Select tasks



Bilingual Executive Processing Advantage	Similar performance across all task types (neutral, congruent, incongruent)	General mechanisms	Non-linguistic Flanker
Conflict Monitoring Advantage	When conflict present (incongruent trials), faster RTs in congruent and neutral trials	Conflict resolution and monitoring	Flanker; Simon; Stroop
Shifting Advantage	Faster RTs in switch trials, leading to smaller switch costs	Task shifting	Color-shape switching; animacy-size
Generalized Cognitive Advantage	Regardless of task, better performance compared to monolinguals	General mechanisms (including working memory and reasoning)	<i>N</i> -back; complex digit span
Bilingual Inhibitory Control Advantage	Faster RTs in incongruent trials, resulting in less interference (improved inhibition)	Inhibition	Flanker; Simon; Stroop

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One way to resolve the problems with the literature might be to achieve an agreement on the mechanisms responsible for the bilingual advantage. It has been suggested that a theoretical foundation is missing and that the majority of studies within the field are guided by task results (e.g., Jared, 2015). Given the complexity of the evidence-base on bilingualism and EF, there is rising support for a more comprehensive, integrated brain-based approach to investigate the impact of bilingualism on EF. Recently, two neurobiologically based theories have attempted to profile the link between language and EF as well as propose the mechanism by which bilingualism could regulate EF abilities.

The first model calls attention to how bilingual ‘brain training’ may nourish the basal ganglia network (a set of cells situated in the center of the brain) which uses inhibitory signals to manage load to the frontal lobe (Stocco, Yamasaki, Natalenko, and Prat, 2014). Structural changes have been evidenced in this network as a consequence of the bilingual experience, for example, adjustments in basal ganglia volumes (see Grundy et al. (2017) for a review). Stocco et al. (2014) refer to the conditional routing model to interpret these

functional changes; this model prioritizes one signal over another through a circuit that carries out selective transfer to the prefrontal cortex. In other words, depending on task demands, the basal ganglia controls the movement of signals to the EF areas in the brain and adapts this information flow (re-routing information) to sustain responses that are task-relevant. The ‘brain training’ model not only highlights the basal ganglia as an underlying mechanism, but also puts forward predictions about particular EF domains that should be subjected to a re-routing practice advantage. Specifically, this model predicts bilingual advantages in selection abilities, response inhibition, flexible switching, and the ability to maintain top-down goals in the face of distractions.

The second theory that addresses the relationship between bilingual language use and EF is the Adaptive Control Hypothesis (ACH) (Green & Abutalebi, 2013). In contrast to the ‘brain training’ model which centers on the role of the basal ganglia in bilingual language processing, the ACH centers on all the regions of the brain involved and suggests that EF domains linked to these regions adjust to particular demands created by specific language or ‘interactional’ contexts. Three interactional contexts are proposed, namely; the single-language context, the dual-language context, and the dense-language context. Each one of these contexts is proposed to place a certain type of demand on different EF domains.

The single-language context involves the use of each of the two languages in separate settings, for instance, using one language at home, and the other at school. Therefore, no switching takes place as the two languages are separated from one another. The single-language context is thus proposed to place demand on sustained attention (i.e., one has to sustain speaking in one language or the other) and interference control (i.e., inhibiting the nontarget interfering language to focus on the target language). These EF domains are linked to the left inferior frontal gyrus, therefore, the single-language context may nurture this region and its associated EF domains.

In contrast to the single-language context, the dense-language context involves the use of two languages across a single sentence, for instance, English-Arabic bilinguals may switch from one language to another in the middle of an utterance or switch back and forth between the two across a sentence. This can typically involve adapting words from one language to adjust or ‘fit’ into the context of the other. The dense-language context is thus proposed to place demand on only one EF domain - opportunistic planning. Connections with the prefrontal cortex and the cerebellum should be strengthened as a result. As the languages are used in a highly flexible and free manner, sustained attention and interference control domains are not exercised in this context.

The most demanding language context for a bilingual individual is the dual-language context, as suggested by Green and Abutalebi (2013). In this context, both languages are used but each language is generally used with different speakers, for instance, speaking one language with co-workers and another with employers (at the same workplace). The dual-language interactional context is proposed to involve especially high demand on the domains of sustained attention, interference control, and flexible switching. Connections between multiple brain regions are sparked, key ones being the prefrontal cortex, the parietal cortex and the basal ganglia network. In a way, the dual-language circumstance is very similar to the bilingual circumstance highlighted by Stocco et al. (2014); the ability to prioritize one language over another, based on the circumstance, underlies the bilingual advantage.

Green and Abutalebi (2013) postulated that bilinguals should outperform monolinguals when task and environmental demands are matched. Specifically, domains including sustained attention, interference control, and flexible switching should be augmented whereas others, such as working memory, should be less impacted. While the dual-language context predicts a bilingual advantage via the exercise of various EF domains, Green and Abutalebi (2013) note that the responsible specific mechanism remains an open question. They also state that bilingual abilities are best demonstrated using a range of measures. The ACH thus offers a theory rooted in language use with transparent predictions that can be subjected to empirical testing. In fact, recent empirical evidence on the diversity of language use in bilinguals seems to lend support to the ACH (Gullifer et al., 2018).

In summary, there is one key difference and several similarities between the two theories reviewed here. While both theories differ in their mechanisms, both presume that two languages are active, both connect language processing to general cognitive processing, and both suggest differences in processing between bilinguals and monolinguals. Despite the lack of extensive empirical testing, both relatively new models offer a basis that takes into consideration theoretical and neurophysiological elements. Further investigation of these models would offer much-needed insight to support or refute these theories, which in turn, enlightens the debate on the mechanisms by which EF domains may be enhanced in bilinguals.

### **3. Bilingualism, autism, and executive function: Study rationale**

The sum of the literature reviewed thus far suggests there are certain EF deficits that can be experienced by autistic children, adolescents and young adults (i.e., interference control,

flexible switching and sustained attention) ([Section 1.1c](#)) which could potentially be ameliorated by an experience like bilingualism ([Section 1.2b](#)), especially when carried out in a dual-language context ([Section 1.2c](#)). Therefore, an investigation at the interface of bilingualism, EF, and autism which explores these particular EF domains in the right interactional context is a highly interesting one. Quality work at this interface has the potential to significantly impact not only theory and knowledge, but also the lives of autistic individuals and their families.

There are rising diagnostic rates of autism and increases in the worldwide bilingual population (de Oliveira, 2015). There are also concerns in the autism community about raising an autistic child bilingually (Hampton, Rabagliati, Sorace & Fletcher-Watson, 2017; Moore & Pérez-Méndez, 2006). Therefore, it is imperative to chart the effects of bilingualism on autism, especially in a domain evidenced to impact quality of life (i.e., EF), as highlighted earlier. Finally, I note that specific evidence on the effects of bilingualism on executive function in autistic children is sparse and is reviewed in the subsequent chapter ([Chapter 3](#)).

#### **4. Overview of the present research**

With only a handful of studies published worldwide to date, our understanding of the impact of bilingualism on the EFs of autistic children remains very limited. Advancing our understanding of the effects of bilingualism on the EFs of autistic children is key to providing better support for linguistic and cognitive development, both of which have been evidenced to impact quality of life. The current work presents five main chapters, each contributing unique findings to the evidence-base surrounding bilingual autistic children.

Chapter 2 outlines the methodology utilized throughout this entire work, given that all the data was collected from the same sample of children, all of whom were recruited from the same geographical location. In Chapter 3, guided by the ACH theoretical framework, I explore the relationship between bilingualism and EF in school-aged children, using directly-assessed, experimental measures of EF. In Chapter 4, I ask the same question but using informant-report measures of executive function, capturing both parent and teacher perspectives on children's abilities. In Chapter 5, I take a step back from bilingualism and bring into focus the EF profiles of my autistic participants, regardless of their language status, examining heterogeneity within the sample. In contrast to Chapter 3 and 4 which employ a group differences design that compares the average performance of autistic participants as a group with the average performance of TD participants as a group, Chapter 5 implements a

multiple case series analysis which captures individual differences in autistic performance across several EF domains.

Taken together, the chapters form an investigation of executive functions profiles in Arabic-English autistic children. To my knowledge, this is the first investigation at this interface to use a multidimensional EF approach – EF was assessed via a combination of direct and informant-based (parent and teacher reports) measures. It is also the first to employ mixed analytic methods (i.e., group and multiple case series analysis). Further new contributions come from the inclusion of sustained attention as a relevant domain of interest. Additionally, this work contributes to the diversification of autism research samples beyond WEIRD (western, educated, industrial, rich, and democratic) samples (Henrich, Heine, & Norenzayan, 2010; Nielsen, Haun, Kärtner, & Legare, 2017). Finally, this work contributes new findings from the targeted investigation of the ACH theory in a non-typical population. In Chapter 7, the overall findings of the study are discussed, to draw conclusions, identify evidence-based implications for families, practitioners, researchers, and chart new areas of bilingualism research in childhood autism.

## Chapter 2: Methods

### 1. Overview of methods in relation to thesis aims

The purpose of this chapter is to describe the methods utilized in this entire work, taking the reader through key decision making processes pertaining to study design, participant matching, test selection, piloting, and finally, the resulting finalized battery of measures. The methodology spans three investigations. The first aim is to explore the impact of bilingualism on the EF skills of autistic children, to test the predictions of the ACH model. Specifically, what is the impact of bilingualism on the EFs selected for their theoretical relevance to bilingualism (i.e., interference control, flexible switching, and sustained attention), in both autistic and non-autistic children? Directly-assessed measures of EF administered at one point in time (Chapter 3 investigation) and informant-report measures that capture parent and teacher perspectives across a wider time span (Chapter 4 investigation) are utilized to address this question.

The second aim is to examine the relationship between bilingualism markers (e.g., language proficiency, language switching, age of acquisition) and EF performance (Chapter 4 investigation). Specifically, is there a relationship between the EF performance and bilingualism markers selected for their relevance to bilingualism? Directly-assessed and informant-report measures of language are utilized to address this question. The third aim is to explore the diversity in the EF profiles of autistic participants, regardless of their language status. Specifically, is there evidence of variability as well as marked variability in the EF profiles of a linguistically-diverse autistic sample? Informant-report measures of autism features are utilized to address this question. All quantitative data collected throughout this doctoral work were sourced from a single participant pool in the United Arab Emirates (UAE).

### 2. Selection of geographical location

There are four key justifications associated with the decision to carry out the research in the UAE. First, the UAE offers a predominantly dual-language switching environment. While Arabic is the leading language, English is broadly accepted as the lingua franca, since the large majority of the country's population (close to 90%) is made up of non-citizens (De Bel-Air, 2015). Therefore, in contrast to regions like the UK with a monolingual majority and

fewer switching contexts, the UAE offers access to a predominantly bilingual population accustomed to frequent switching between two languages within the same context (with either the same speakers or different speakers). As per the ACH (the theoretical model under investigation in this work), this type of interactional context places the highest demand on the EFs selected.

Second, investigations with Arabic-speaking populations are of global relevance. First, Arabic is in the top five most spoken languages of the world, with native speakers exceeding 240 million (Adams & Fleck, 2015). Second, given that most psychological research is informed by WEIRD (western, educated, industrial, rich, and democratic) populations (Henrich, Heine, & Norenzayan, 2010; Nielsen, Haun, Kärtner, & Legare, 2017), investigations with Arabic-speaking populations offer a valuable opportunity towards the diversification of autism research.

Third, for over a decade, I have actively delivered educational and recreational services aimed at supporting autistic children and their families in the UAE. Therefore, relevant regulatory knowledge, networks and recruitment pathways were relatively well established for data collection in this country.

Fourth, the UAE boasts a strong inclusion policy for autistic individuals, among other neurodivergent individuals, or – as they are officially referred to in UAE legislation and mainstream society – ‘People of Determination / أصحاب الهمم’. The term was launched under the national policy for empowering neurodivergent members of the community (UAE Ministry of Community Development, 2017). The national policy guarantees inclusion rights in mainstream schools, the workforce, and society at large. It also encourages nation-wide facilitation of quality initiatives – including research initiatives – aimed at improving the quality of life of autistic individuals. Furthermore, the ‘UAE Vision 2021’ was developed in 2010 to chart six key priority areas for the nation and respective plans to realize them by the year 2021; one of which is, developing world-class healthcare and education (Al Hashemi, 2016, p.258). Therefore, given the government’s vision, mission, and commitment to meet the educational, social, emotional and vocational needs of its ‘People of Determination’, one can expect to receive the support of regulatory, educational, and clinical entities across the Emirates, to carry out the current doctoral research which aims to contribute to evidence-based practices for ‘People of Determination’.

On the other hand, there are two noteworthy limitations with carrying out this project in the UAE. First, it can be challenging to recruit monolinguals (particularly monolingual TD children) in an environment like the UAE which is predominantly bilingual. Second, despite

research confidentiality, some families of autistic children might feel unable to participate for fear of identification. Research in the UAE has revealed stigma-associated discrimination faced by autistic families (Crabtree, 2007; Sopaul, 2019).

In conclusion, monolingual recruitment and familial stigmas surrounding autism were two notable key challenges of collecting data in the UAE. However, access to a large sample of individuals exposed to Arabic and English, a rich language switching context, strong inclusion environments for autistic children, and well-established regulatory and recruitment networks were the key advantages of carrying out this research in the UAE.

### **3. Participants**

#### **A. Recruitment strategy**

Eight months prior to the launch of data collection, I invested in a two-week research trip to the UAE. The field trip was strategically scheduled during autism awareness month (April 2017) and played a pivotal role in determining the feasibility of carrying out this research and thoroughly preparing for ethics-related application processes in the UAE.

The first aim was to acquire an educated estimate of the participant pool size in the UAE. To do this, I shortlisted and contacted key establishments in the UAE that serve ‘People of Determination’ and their families, to get a rough estimate of the number of autistic children they serve who met broad research eligibility criteria. I also attended key autism awareness events in the capital (Abu Dhabi) that offered networking and community engagement opportunities, which were organized and attended by centers and mainstream schools that serve autistic children and their families.

The second aim was to make contact with the regulatory bodies responsible for ethics-related approvals in order to carry out this research in the UAE. I identified two key regulatory bodies to approach for approval; namely, the Abu Dhabi Department of Education and Knowledge (ADEK) and the UAE Ministry of Community Development (UAE MOCD). The former is the regulatory educational authority for Abu Dhabi, the UAE’s largest emirate and capital city, and typically regulates education across private and public schools. The latter is the regulatory authority for educational and rehabilitation centers for people of determination’ centers across the UAE. I visited ADEK’s premises to meet with a member of the research team that processes ethics applications. I received a briefing on how to submit an ethics application via ADEK’s research portal, follow-up contacts, and what to expect next. I also met with a team member who works on inclusion programs for ‘People of



Determination’ at mainstream schools, in an attempt to capture a realistic estimate of the participant pool size in Abu Dhabi. He confirmed I could request access to a list of mainstream schools in Abu Dhabi that integrate autistic children in my desired age group. He also reassuringly confirmed that the large majority of private and public schools in Abu Dhabi enrolled autistic children as part of their student body.

Similarly, I paid a visit to the UAE MOCD premises to thoroughly inquire after their ethics procedures and secure a local contact for any follow up inquiries. I ascertained that their ethical procedure involved sending an email, with research-relevant attachments to an in-charge department. A complete summary of required ethical approvals is described in the next section.

## **B. Ethics and access**

The current project secured five types of approvals necessary to carry out this research across the UAE. First, UK ethics approval (granted by the University of Edinburgh, School of Philosophy, Psychology and Language Sciences, Application 102-1718/2). Second, UAE ethics approval (granted by ADEK to access mainstream schools). Third, UAE ethics approval (granted by the UAE MOCD to access ‘People of Determination’ centers). Fourth, UAE sub-regulatory approval (granted by ADEK’s Private School Sector) to access a relevant list of private schools with student samples that match my inclusion criteria. Fifth, UAE sub-regulatory approval (granted by ADEK’s Public School Sector) to access a relevant list of public schools with student samples that match my inclusion criteria. Table 2 displays the list of approvals obtained for this UAE-UK doctoral project.

**Table 2.** Approvals obtained for 2016-2020 UAE-UK doctoral project

<b>Institution</b>	<b>Type</b>	<b>Submitted</b>	<b>Approved</b>
University of Edinburgh	Ethics	07.11.17	30.11.17
Abu Dhabi Department of Education and Knowledge (ADEK) – Main.	Ethics	07.12.17	05.02.18
Abu Dhabi Department of Education and Knowledge (ADEK) – Public Schools Sector.	Information	12.02.18	12.02.18
Abu Dhabi Department of Education and Knowledge (ADEK) – Private Schools Sector.	Information	20.02.18	21.02.18

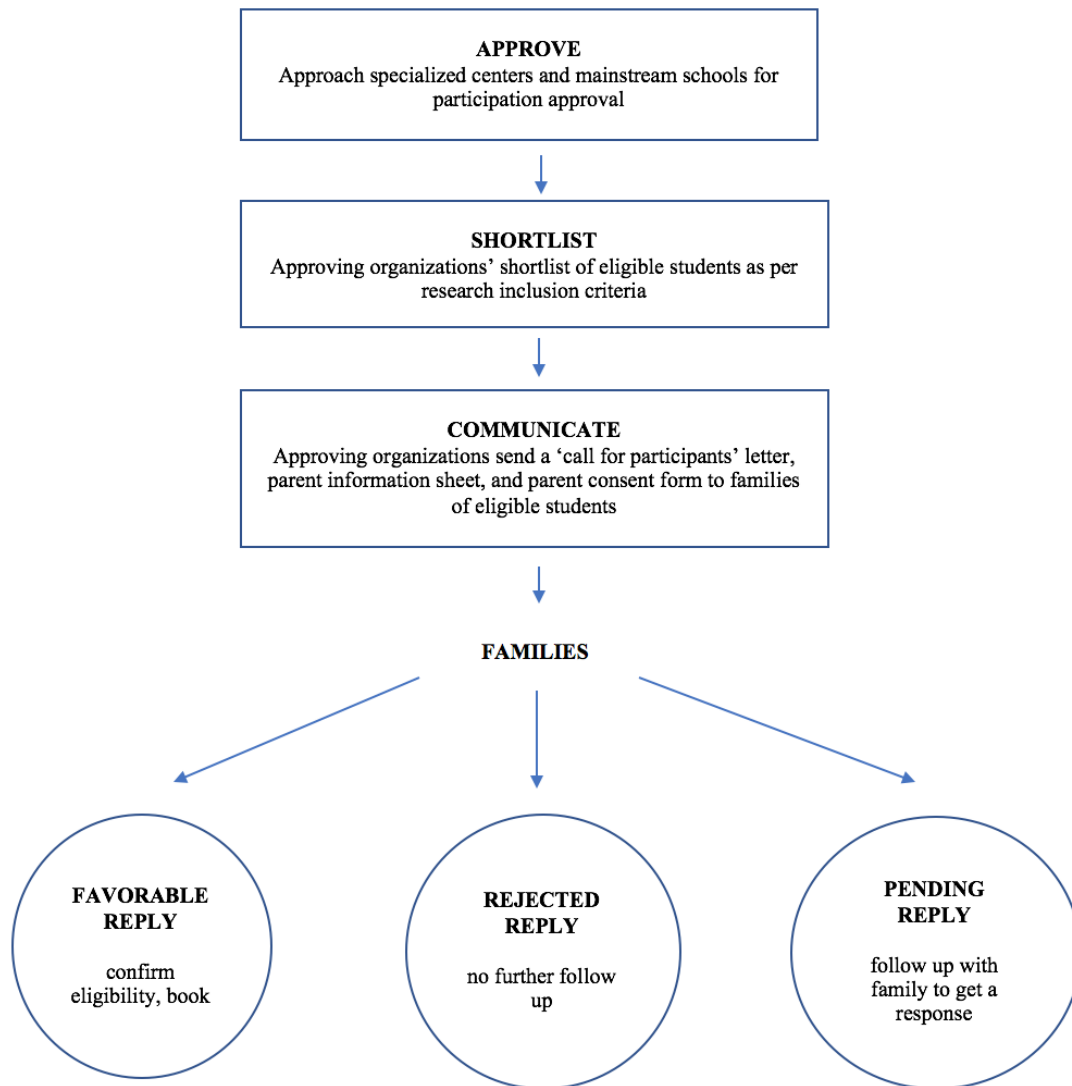
### **C. Target sample size**

There were no relevant studies that examined the interface between bilingualism, autism and EF to allow me to determine expected effect sizes and a target sample size. Therefore, a robust a priori power calculation was not possible. Furthermore, testing in the UAE imposes a recruitment challenge with respect to securing monolinguals (particularly monolingual TD children) as the UAE population is predominantly bilingual. Considering the lack of a valid a priori basis in the literature, our target samples, and the recruitment challenges in the UAE, a decision was made to recruit the largest sample size possible and pursue post-hoc power analysis on the final sample size secured post data collection to inform data interpretation (this is addressed in each subsequent investigation).

### **D. Participant recruitment**

*At a glance.* I made every effort to recruit the maximum number of participants possible across the Emirates throughout 13 months of data collection. I pursued this goal by arranging meetings with recruitment-relevant bodies, giving presentations at local conferences (press, academic and educational types) and workshops, actively participating in key autism awareness events and community engagement events, securing media coverage to announce the nation-wide launch of my doctoral research (I was accepted as a guest on two radio channels), and circulating my research on social media platforms (e.g., Facebook and Twitter). The end result was the cooperation of 22 institutions (e.g., centers, mainstream schools, and universities), across three Emirates (i.e., Abu Dhabi, Dubai, and Sharjah), with data collected from up to 120 participants, within 13 months (March 2018 – April 2019).

*Procedure.* Figure 1.1 depicts the main recruitment procedure followed.



**Figure 1.1** Primary research recruitment procedure

In the event any organization could not involve its staff in shortlisting eligible students, the following procedure was followed:

- 1- Centers and schools were asked to circulate study information (a call for research participants) via their newsletter / general online mailing list.
- 2- Posters (a call for research participants) were put up in the welcome area of respective schools and centers.
- 3- Families were approached via relevant autistic support groups on Facebook.

Families who contacted me having read a poster, seen my research website or read my email were treated as having returned an Expression of Interest form and I noted down the relevant information required by the form (e.g., family name, contact details, permission to phone).

*Initial contact.* As described above, families who responded favorably to the participant call did so via text, email, phone call or sent back a consent form signed to confirm their willingness to participate. I then asked the family how they want to be contacted to discuss further details (telephone call, email, in-person at the center/school, etc.) and executed their preferred option for contact. If the family confirmed their interest in being involved, I then scheduled a meeting to take informed consent from parents (if not already collected) and assent from children, and carry out the assessments.

*Informed consent.* Once the family had agreed to participate in the study, informed written consent was obtained. The parent(s)/caregiver(s) giving consent had to read through the consent form and confirm understanding by responding to each item. The child was given a child assent form (asked to circle a happy face if they did not mind playing games with me or asked to circle a sad face if they preferred not to play with me) and, as far as possible, helped to understand their involvement in the study.

## **E. Inclusion and exclusion criteria**

In this section and the following section, key matching, inclusion and exclusion criteria are listed along with a review of the rationale for the selection process. Due to the anticipated recruitment challenges mentioned earlier, inclusion and exclusion factors were carefully considered and minimized to ensure the maximum possible sample size for the research.

*Autistic group.* Children included into the study were aged 5-12 years, with a formal autism diagnosis confirmed by center / school / parent (i.e., DSM-IV or DSM-5). At least one parent / carer needed to be able to read and understand the information presented in forms and assessments in either Arabic or English. Autistic children were also screened for inclusion on Raven's Colored Progressive Matrices. For the first investigation; Chapter 3 (directly-assessed EF), I required a non-verbal IQ of at least 'intellectually average'. For the second investigation; Chapter 4 (informant-report measures), children with more inclusive IQ ranges were included in the analyses. Children with uncorrected visual or hearing deficits and/or with other cognitive disabilities which present themselves in addition to autism / co-morbidity (e.g., ADHD) were excluded.

Determination of bilingual language status was achieved based on a synthesis of the following markers, as indicated by a parent-rated language experience and proficiency questionnaire (The Child Language Experience and Proficiency Questionnaire (Marian, Blumenfeld, & Kaushanskaya, 2007) as well as an expressive vocabulary test (Picture Naming Test (Kharkhurin, 2008)) administered in English and Arabic: (a) > 20% of current exposure to each of the two languages at home or school, according to parent report, (b) > 20% of current active speaking in each of the two languages at home or school, according to parent report, (c) > 20% proficiency score (24 correct responses out of a possible total of 120) in each of the two languages according to a direct expressive vocabulary measure, rated by the researcher. Language proficiency was assessed based on the accuracy of participants' responses to the objects in the Picture Naming Test.

Bilinguals were categorized into low proficiency (21% - 39%), medium proficiency (40% - 65%) and high proficiency (66% - 100%) bilinguals (Marian et al., 2007). The 20% minimum exposure cutoff to determine bilingual status was based on the 20% threshold hypothesis established by Pearson et al. (1997), which claims that children who hear less than 20% of their input in a given language are often unwilling to speak that language. In line with this hypothesis, Hoff et al. (2012) suggest that 20% is an absolute minimum of input for a child to be able to use a language. This threshold has also been adopted by recent studies published in the bilingualism and autism research interface (e.g., Gonzalez-Barrero & Nadig, 2017).

Determination of monolingual language status was achieved based on a synthesis of the following markers: (a) had not been exposed to a language other than Arabic (or English if their first language was English) for more than 20% of their lifetime, (b) if exposed to a second language, < 20% of current active speaking at home or school, according to parent report, (c) if exposed to a second language, < 20% proficiency score according to a direct expressive vocabulary measure, rated by the researcher.

*TD group.* Children included into the study were aged 5-12 years. At least one parent / carer needed to be able to read and understand the information presented in forms and assessments in either Arabic or English. Children with uncorrected visual or hearing deficits and/or with cognitive disabilities were excluded. Determination of bilingual and monolingual language status was identical to the above procedure for autistic children.

## **F. Matching criteria**

Gender matching was deemed unfeasible given the anticipated recruitment challenges and their implications for sample size, as well as the anticipated rate of gender imbalance in the autistic group (male-dominant sample). This would have had a detrimental effect on sample size. The following section addresses three selected matching criteria, namely, IQ, age, and socioeconomic status (SES).

***IQ.*** As highlighted earlier, participants were only matched on IQ in the first EF investigation which involved performance on an extensive EF battery (Chapter 3). This was necessary as the tasks were suited for more cognitively-abled participants. I also wanted to rule out the confounds of intellectual disability, thus attributing the findings of group differences to diagnostic group (autism) only.

***Age.*** With respect to sample characteristics, particularly age, I chose to include children aged 5-12 years as I am investigating EF in childhood. This is in line with Brocki and Bohlin's (2004) proposition that child EF matures in three active phases: early childhood (6-8 years), middle childhood (9-12 years), and early adolescence (12+ years). Therefore, my age group of 5-12 years captures childhood in its early and middle phase (pre-adolescence).

The development of EFs takes place over several years, beginning in early life and extending to adolescence (Gathercole, Pickering, Knight, et al., 2004). This finding is supported by evidence from brain studies which indicates that the prefrontal cortex is one of the last regions of the brain to reach maturity in childhood and adolescence and one of the first regions of the brain to diminish in old age (Diamond, 2002). An established body of research focusing on children provides evidence of distinct adjustments in EF development with age (Engel-Yeger et al., 2009; Huizinga et al., 2006; Luciana et al., 2005), with 12-year old children performing at an adult level in inhibitory control (van den Wildenberg & van der Molen, 2004) and flexible switching (Kray et al., 2004) domains. While some studies also provided evidence of EF adjustments post 12 years of age (e.g., Theodoraki et al., 2019), there is evidence to suggest unique EF growth during the childhood phase of life.

It is also worth noting that EF does not develop in the same way across EF domains. While interference control abilities tends to peak between the ages of 6 and 10 years, flexible switching abilities start to take form by the age of 3 with a marked increase in growth after the age of 7. Both EF domains continue to grow to adolescence (Best & Miller, 2010; Jurado & Rosselli, 2007).

The measures selected for this current work were deemed suitable for children with a minimum age of 5 years and a maximum age of 10 to 12 years (suggesting we could conceptualize EF between these ages in a continuous way). Examining children over the age

of 12 years would require testing with different versions of the same task (different task properties) suited for testing with older child populations, potentially complicating comparisons and result interpretation.

*Socioeconomic status (SES).* Consistent links between SES and EF performance have been identified in the literature, with a number of robust investigations revealing an advantage for children from high SES backgrounds, relative to low SES backgrounds (Buckner et al., 2003; Howse et al., 2003; Waber et al., 2006). Waber et al. (2006) attributed this to several factors. First, they noted there are likely differences in the supply of resources between groups, for instance, in terms of access to learning materials. Second, they highlighted potential differences in familial and environmental circumstances. Third, they explained this finding in terms of teacher expectations; low expectations of children from low SES backgrounds. A study by Farah et al. (2006) which revealed significant differences between high SES and low SES children on working memory and inhibitory control abilities, suggested that it was factors associated with low SES such as increased stress and poorer nutrition that underlie EF difficulties, rather than low SES. Furthermore, children from low SES backgrounds have been found to perform optimally on visually-friendly tasks within minimal linguistic demands. A study by Engel-Yeger et al. (2009) revealed equivalent performance between high SES and low SES children on an EF task containing simple language and imagery.

With respect to evidence on the effects of bilingualism and SES on EF, most studies reporting bilingual advantages in children have relied on middle-class samples. However, bilingual advantages in EF have also been reported for children from low SES backgrounds. To illustrate, the latter, Carlson and Meltzoff (2008) revealed an interference control advantage for low SES bilinguals, relative to high SES monolinguals, once vocabulary was statistically controlled for. The findings suggest that one factor does not prevent the influence of the other. Another study by Mezzacappa (2004), with a larger sample, supports this finding. Low SES bilinguals outperformed high SES children on interference control. While bilingualism was not formally assessed in this study, the authors noted that some children were considered bilingual based on home language use information.

It is important to note, however, that different studies apply different measurements to SES (i.e., income vs. education) which can reflect different SES outcomes for bilingual samples depending on the metric used. For the current work, a decision was made to assess SES as both a continuous and categorical variable via: (a) paternal and maternal continuous years of education, and (b) paternal and maternal highest education level.

## G. Participant characteristics: Final sample

Ninety-three children aged 5 to 12 years were recruited into the study study ( $M = 9.16$  years,  $SD = 23.85$  months). Monolingual children spoke either English or Arabic, and bilingual children spoke both English and Arabic. Participants were matched on age and socioeconomic status factors. Table 3 and Figure 1.2 display key demographic information.

**Table 3.** Thesis research sample: Participant demographics by group

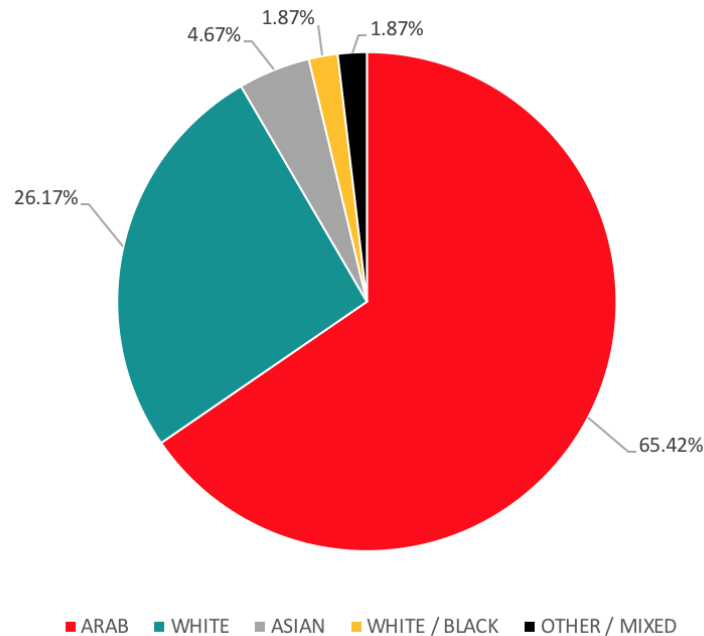
	Monolingual Autistic (N=10) M (SD)	Monolingual TD (N=32) M (SD)	Bilingual Autistic (N=17) M (SD)	Bilingual TD (N=34) M (SD)
Participant age ( <i>months</i> )	99.11 (22.78)	111.03 (27.74)	115.56 (24.24)	110.50 (19.63)
Non-verbal IQ ( <i>score</i> )	27.90 (3.75)	30.63 (4.31)	30.24 (3.52)	30.44 (3.59)
Paternal education level	5.88 (1.24)	6.40 (1.24)	5.20 (1.47)	6.26 (1.10)
Paternal education ( <i>years</i> )	17.13 (3.31)	18.10 (3.13)	16.20 (1.98)	17.53 (1.63)
Maternal education level	5.50 (1.77)	5.83 (1.26)	4.92 (1.16)	5.82 (0.86)
Maternal education ( <i>years</i> )	17.00 (3.33)	16.67 (1.53)	15.83 (1.52)	16.88 (1.06)
Receptive Vocab English	107.63 (38.77)	110.91 (26.94)	86.92 (23.98)	120.26 (34.93)
Receptive Vocab Arabic	-	-	50.45 (25.63)	71.16 (24.39)
Expressive Vocab English	88.40 (32.51)	110.94 (7.23)	74.87 (19.17)	100.48 (16.50)
Expressive Vocab Arabic	-	-	61.40 (22.73)	65.39 (19.20)
Autistic Symptomatology	69.80 (16.14)	-	67.91 (10.28)	-
Gender (M/F)	8/2	13/19	10/7	8/26

*Note.* Education level = 0 (none), 1 (less than high school), 2 (high school), 3 (professional training), 4 (partial college), 5 (college), 6 (some graduate), 7 (masters), 8 (doctorate); Autistic Symptomatology = as assessed by the Social Responsiveness Scale-2: 76 or higher ("severe deficits"), 66 to 75 ("moderate deficits"), 60 to 65 ("mild to moderate



deficits”), 59 and below (“no deficits”); M = mean; SD = standard deviation; TD = typically developing; CPM = nonverbal IQ standard score from the Colored Progressive Matrices.

**Figure 1.2.** Participant Ethnicity Breakdown



#### 4. Design

The current work adopts a 2 x 2 (four-group) design. An evaluation of the key strengths and weaknesses of a two-group (autistic bilingual, autistic monolingual) versus four-group (autistic bilingual, autistic monolingual, TD bilingual, TD monolingual) design was undertaken to determine the most suitable design for the current work.

One major weakness in using a two-group design focusing on an autistic sample only, is the lack of insight faced when interpreting research findings in the absence of a control group (TD group). With a four-group design, however, one can meaningfully attempt to make sense of study outcomes in the autistic group in relation to study outcomes in a TD group as well; for example, when faced with findings that point to a bilingual advantage in the TD group but not the autistic group, or vice-versa.

Another major weakness of a two-group design is the heightened risk of obtaining low sample size numbers, given: 1) the multi-layered inclusion criteria already in place, 2) autistic children are a hard-to-reach research sample, 3) bilinguals are more prevalent than

monolinguals in language environments like the UAE, therefore, even lower sample size numbers are anticipated with the monolingual group. A four-group design, however, mitigates this risk to an extent as it involves data collection with TD groups as well (more participants / increased sample size), who are generally easier-to-access population for research (no additional procedures to access TD groups as ethics grants access to all schools and children).

The study design was also reviewed in consultation with other active researchers in this field, in the UK and Canada. Therefore, while a four-group design was more time consuming (as sample size increases, data collection time increases) and more costly (material costs are higher as I budget for more participants) relative to a two-group design, it was the stronger design out of the two in terms of sample pool, power, and research insights. A decision was thus made to adopt a 2 x 2 (four-group) design.

## **5. Materials**

### **A. Measure selection criteria**

As a whole, this work aims to measure the following domains: Executive functions, expressive and receptive language, language history and use, and autism profiles. Across most of these domains, a range of measurement types (i.e., direct measures, informant-report measures) are used. To guide my initial “shortlist” of measures for use in this research, selection criteria were developed. These were derived from my review of the relevant literature and consultation with autism and bilingualism researchers on accessibility, feasibility, and acceptability of different measures.

The first selection criterion involved sourcing computerized tasks as they present reduced verbal and social task demands for autistic children. They also have potential for more standardized administration and are sensitive to the recording of reaction times. Finally, they are generally time-saving when it comes to administration and more cost effective (free of charge) than non-computerized measures (i.e., score sheets). In addition, I specified a touchscreen response option to avoid any fine motor challenges associated with operating a mouse.

The second selection criterion was suitability for my study design and sample: children, 5-12 years of age, etc. I sought tasks that do not take up relatively long periods of time to complete – ideally 15 minutes or less so that the total session time would not exceed 3 hours. I also considered suitability of use with children who are more cognitively able as

this pertains to my target sample. Due to limited research funding, I also considered affordability. Finally, I considered the availability of tasks in both English and Arabic, to suit my research context. In case of unavailability of any task also meeting the other criteria to an adequate level, translation of a suitable English task was to be carried out.

The third selection criterion was capacity to detect meaningful differences. I aimed to select tasks that were sensitive to subtle differences and were suitable to explore more than just group differences. I also required strong psychometric properties, such as reported reliability and validity.

I applied all these selection criteria to a selection of measures capturing the desired EF constructs, with minimal to no undesired EF constructs at play. For example, tasks needed to have a limited working memory component as autistic children have been shown to perform worse on EF tasks that involve demanding working memory skills. For inhibition, the task needs to, ideally, measure interference control, and not response inhibition. For flexible switching, tasks with predictable or unpredictable switching can affect performance of autistic children. Care was taken to select tasks with cues and predictable switching as autistic children have been evidenced to perform within the normal range in this EF domain when performing an explicit (clear cues) task.

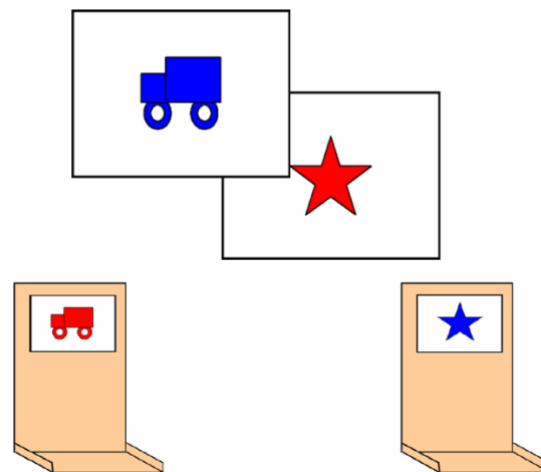
## **B. Properties and procedure: Direct measures of executive functions**

Here I review the shortlisted tasks for each domain of measurement, specifically reviewing how the tasks meet my selection criteria, or highlighting instances where this is not entirely the case. I will also outline the standard procedure for administration and scoring of the task, but details of how variables were derived and data were processed for this study will be covered within individual subsequent results chapters. All measures were administered using a touchscreen laptop, a Toshiba Portege m780-10v. All data collected with E-Prime 2.0 software was saved and generated using e-DataAid. Only one task ran with visual basic (DCCS).

*Flexible switching.* Two tasks were shortlisted, namely the Dimensional Change Card Sorting Task (DCCS) (Diamond, Carlson, & Beck, 2005) and the Switch Task (Rubia et al., 2007) to assess flexible switching. They were shortlisted as they met my criteria. In particular, good test retest reliability (reliability coefficient of .76), has been reported for the DCCS (Beck et al., 2011). An additional advantage is that both tasks are highly structured, with information on when to switch rules for sorting stimuli. These elements of task

explicitness and task structure were important in selecting a task for investigating flexible switching in children with autism as per key findings reported in the autism literature. Furthermore, both these tasks involve minimal working memory demands, which is equally important to consider when selecting flexible switching tasks for an autistic population.

*DCCS procedure:* On this visual basic version of the task, participants had the option to respond using the mousepad or by touching the screen. There were six phases to this task. In phase 1 (i.e., demonstration), the task is introduced to the participants. They are told they will play two games, a color game and a shape game. Then they are told they will sort some images according to the type of game they are playing. The type of game is indicated by cues at the top of the screen: a rainbow cue indicates the color game and a shapes cue indicates the shape game. They are told: “In the color game, drag all the blue images here (using my index finger as a guide across the screen), and all the red images here. In the shape game, drag all the stars here, and all the trucks here. I want you to keep going even if you make a mistake”.

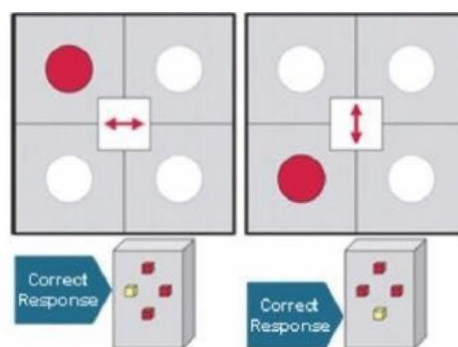


**Figure 1.3** Flexible Switching; Dimensional Change Card Sort Task (DCCS) (cards are to be sorted by shape or color)

In phase 2 (i.e., practice), participants are requested to perform the task, based upon which they received oral feedback. The images are presented indefinitely until a response is made. There are 2 practice trials for the shape game, each repeated until correct responses are made. Likewise, there are 2 practice trials for the color game, each repeated until correct responses are made. In phase 3 (i.e., pre-switch, 6 trials), the rules of the game were restated with the objective of reducing working memory demands for participants. Participants are

then asked to sort the image based on the rule given (i.e., color), with 5 out of 6 correct trials needed to pass. No oral feedback was provided. In phase 4 (i.e., post-switch, 6 trials), participants were told: “okay, we are not going to play the color game anymore; we are going to play the shape game now. Remember the shape game?”. Children were thus expected to disengage from the previous rule, and sort by the new rule. Rules of the game were restated and participants are then asked to sort the image based on the rule given (i.e., shape), with 5 out of 6 correct trials needed to pass. The next phase was more complex. In phase 5 (i.e., mixed), participants were told: “okay, we are going to play a mix of shape AND color games now. If you see a rainbow cue, sort by color. If you see a shapes cue, sort by shape”. There are 2 practice trials for the mixed condition (1 shape game trial, 1 color game trial). At least one correct response is required to proceed with the mixed trials (12 trials) in phase 6, with 9 out of 12 trials needed to pass. Outcome variables include accuracy, switch costs (i.e., the mean reaction time of the first two trials from the post-switch phase minus the mean reaction time of the last two trials from the pre-switch phase), as well as mean RTs in the pre-switch, post-switch, and mixed trials condition. For the mixed condition, only correct trials and trials with RT > 200 ms were considered (Diamond & Kirkham, 2005).

*The Switch Task procedure:* In this task, children are asked to look at a grid that is split into four squares. At the center of the grid, a double-headed arrow is located either vertically or horizontally. This visual is presented for 1600 ms, after which a red dot comes into sight, located in any of the four grid squares. When the double-headed arrow is displayed horizontally, participants are asked to indicate using right and left keys respectively, whether the red dot was in the right or left quadrant of the grid. They are required to do this after the 1600-ms presentation time has passed and a blank screen appeared for 800 ms. There were several repeat trials for this visual with trials lasting 2.4 seconds in total.

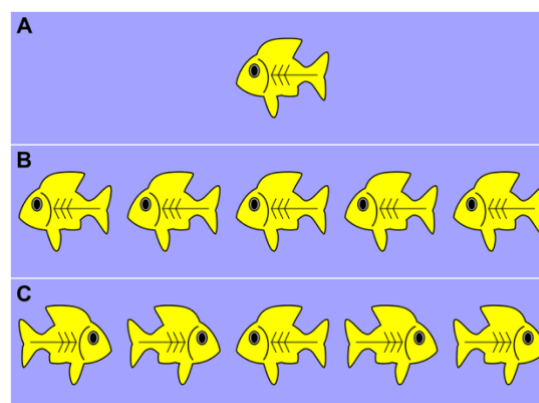


**Figure 1.4** Flexible Switching; Switch Task (arrows are displayed either vertically or horizontally)

These trials were followed by a switch trial, a trial where the arrow is now positioned vertically. Using top and bottom keys, children were asked to indicate whether the red rot was in the upper or lower quadrant. Several repeat trials were undertaken which were then followed by a switch to the old rule (i.e., horizontal arrow), and so on – 128 trials were completed with high frequency repeat trials (91) mixed with low frequency (37) switch trials. Outcome variables included the switch cost or effect (mean reaction time to repeat trials – mean reaction time to switch trials).

*Interference control.* Two tasks were shortlisted to assess interference control, namely the Flanker Task (Rueda et al., 2004) and the Simon Task (di Pellegrino, Ciaramelli, & Làadavas, 2007; Simon, 1969). They were shortlisted as they met my key criteria. In particular, good test-retest reliability has been reported for the Flanker Task (reliability coefficient of .91) and Simon Task (reliability coefficient of .69) (Wostmann et al., 2013). Most importantly, both tasks are proposed to tap into elements of interference control; the distractor interference and spatial interference respectively.

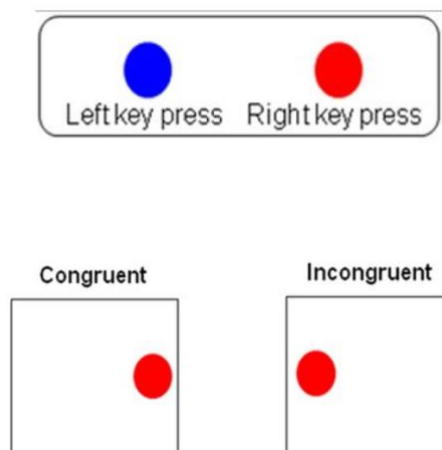
*Fish Flanker Task procedure.* In this test, a screen with a bright background displays a central fixation cross; the target either being a single yellow fish or a row of five fish that are located above or below the fixation.



**Figure 1.5** Interference Control; Fish Flanker Task (row A is neutral; row B is congruent; row C is incongruent)

Participants are asked to “feed the fish” by pressing the mouse button (left or right) that matches the direction that the middle fish target is facing and ignore distracting fish. The fish is flanked by two fishes pointing in the same direction (i.e., congruent condition; 16 trials) or in the opposite direction (i.e., incongruent condition; 16 items). There are 4 practice trials, 2 for each condition. A total of 48 trials are presented, with 24 trials for each condition. Each trial was preceded by a 500-ms fixation cross, and once a response is made, a blank screen appeared for 500 ms. Outcome variables included accuracy and reaction time.

*Simon Task procedure.* The Simon task consists of trials that display either a red or blue colored circle on a white screen (appearing either right or left of the screen). Participants are asked to respond according to one feature of a stimuli (i.e., color) by responding using the corresponding key (right or left; they keys are not marked in any color), while ignoring another feature of the stimuli (i.e., its location on the screen). For example, participants are told: “When you see red, click right – when you see blue, click left. Try not to make too many errors but don’t worry about that, if you make a mistake, just keep going!”. The response made is either congruent or incongruent with respect to the key with which the responses should be made.



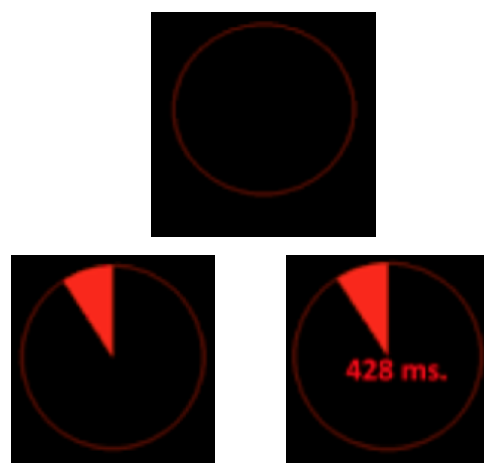
**Figure 1.6** Interference Control; Simon Task (red; right key (congruent); red; left key (incongruent))

The task consistent of 10 practice trials and 56 experimental trials. For the practice trials, oral feedback is given on each trial but no feedback is shared across the experimental

trials. The main outcome measures are reaction times (congruent and incongruent) and Simon effect (i.e., mean incongruent RT / mean congruent RT).

*Sustained attention.* Two tasks were shortlisted, namely the Psychomotor Vigilance Task (PVT) (Lara, Madrid, & Correa, 2014) and the Test of Everyday Attention for Children-2 ed. (TEA-Ch2) (Manly, Robertson, Anderson, & Nimmo-Smith, 1999) to capture sustained attention. They were shortlisted as they met key criteria. In particular, high test retest reliability (reliability coefficient of .84) has been reported for the PVT (Kushida, 2005; Wilson et al., 2010) and adequate test retest reliability (reliability coefficient > .60) has been reported for SART on the TEA-Ch2 (Manly et al., 1999).

*PVT procedure.* In this task, a circle with red borders is presented centrally on a black background. Then, after a certain time (randomly ranging from 2 to 10 seconds), the circle starts to fill up in red in anti-clockwise motion, and participants are asked to press the spacebar (or touch the circle on the screen) as soon as they see it. Participants are instructed to: “Press the spacebar as soon as you see the color red. Remember, only press the spacebar when you see the color turn red”. Once the participants respond (with a click of the mousepad or index finger touch), their trial reaction time is displayed on the screen momentarily. If a response was made too soon (click or touch without a red signal) or a response was not made at all, a feedback saying “too quick” is displayed on the screen before the next trial launches. A total of 88 trials are produced in the 10-minute task, with outcome measures being reaction time mean, number of lapses (missed responses), and number of false starts (anticipated responses, RT <100 ms).



**Figure 1.7** Sustained Attention; Psychomotor Vigilance Task (PVT) (live trial, RT = 428 ms)

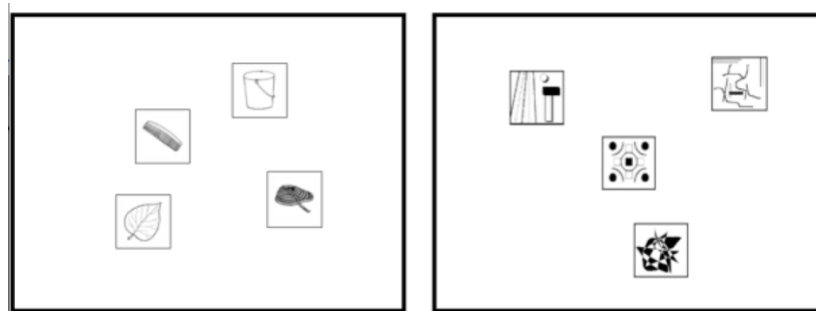


*TEA-Ch2 procedure:* In this task, a set of shapes are presented sequentially on a white background. Participants are asked to respond as quickly as possible to a series of shapes (displayed at the rate of 1 per 1.15 seconds) (i.e., circle, square) by clicking a response key – however, they are asked to withhold from making a response when a certain shape appeared (i.e., triangle). Within a 60-cm viewing distance, participants are instructed to: “look at the shapes that appear one after the other on the screen. I want you to press the spacebar after every shape, like this, but I don’t want you to press the spacebar when you see a triangle.

Press the spacebar after every shape, except the triangle. If you make a mistake, don’t worry, just keep going and remember what I told you”. There are 20 no-go items with outcome measures being accuracy and reaction times.

*Working memory.* Two tasks were shortlisted to assess working memory, namely the Self-Ordered Pointing Task (SOPT) (Cragg & Nation, 2007; Macpherson, Phillips, & Della Sala, 2002) and the Frog Matrices Task (FMT) (Morales et al., 2012). They were shortlisted as they met all key eligibility criteria. In particular, findings on the abstract version of the SOPT report very good test-retest reliability (reliability coefficient of .82) for total errors (Ross et al., 2007).

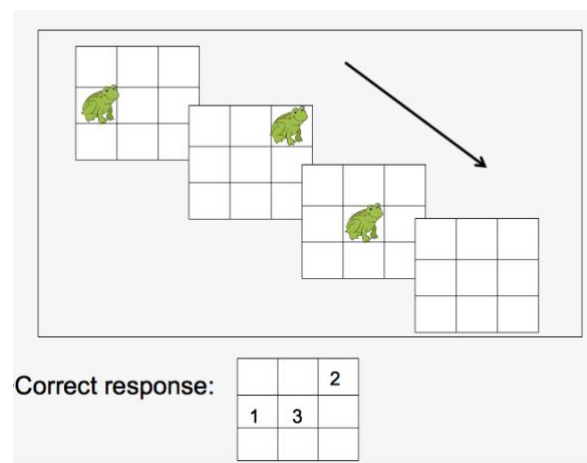
*SOPT procedure.* Object and abstract picture versions of the SOPT were administered. The SOPT assesses the ability to arrange, perform, and monitor a sequence of responses. In both versions, participants are presented with an array of black and white pictures of objects or abstract pictures. Participants are repeatedly presented with the array and instructed to choose one of the items in the array by touching the screen, each time choosing an item that has not been previously selected. Therefore, participants have to monitor their previous choices while they prepare each new response. The position of the items changes across presentations.



**Figure 1.8** Working Memory; Self-Ordered Pointing Task (SOPT) (set size 4; object version (left), abstract version (right))

Participants perform 3 trials containing 4 pictures each (i.e., practice trials), followed by 3 trials containing 6 pictures each, then 3 trials containing 8 pictures each, and finally, 3 trials containing 10 pictures each. For each trial, the array is presented the same number of times as the set size (e.g., for a trial with 10 pictures, the array is presented 10 items). The outcome variables are SOPT mean errors for each set size.

*Frog Matrices Task (FMT)*. In this task, children are shown a 3 x 3 matrix (a total of nine cells) and told: “each cell is a pond in which frogs had been resting, you need to remember which ponds had frogs in them”.



**Figure 1.9** Working Memory; Frog Matrices Task (FMT) (simultaneous condition)

There were two conditions; sequential presentation (frogs are appear one by one) and simultaneous presentation (frogs appear as a group). In the sequential condition, children needed to remember which ponds had frogs in them but in the correct order. In the simultaneous condition, frogs appear for 2000 ms, and then the matrix goes blank for another 2000 ms, before a soft bell sound strikes to let the child know they should respond now. To respond, children touch the screen to show the locations that had a frog. The test starts with just two frogs and adds one frog every second trial, reaching a maximum set / string of 6. I demonstrate the task first and administer two practice blocks before moving on to the experimental trials. There are 5 trials for each of the presentations. Outcome variables include accuracy (correct frog) and order (correct sequence).

### **C. Properties and procedure: Indirect measures of executive functions**

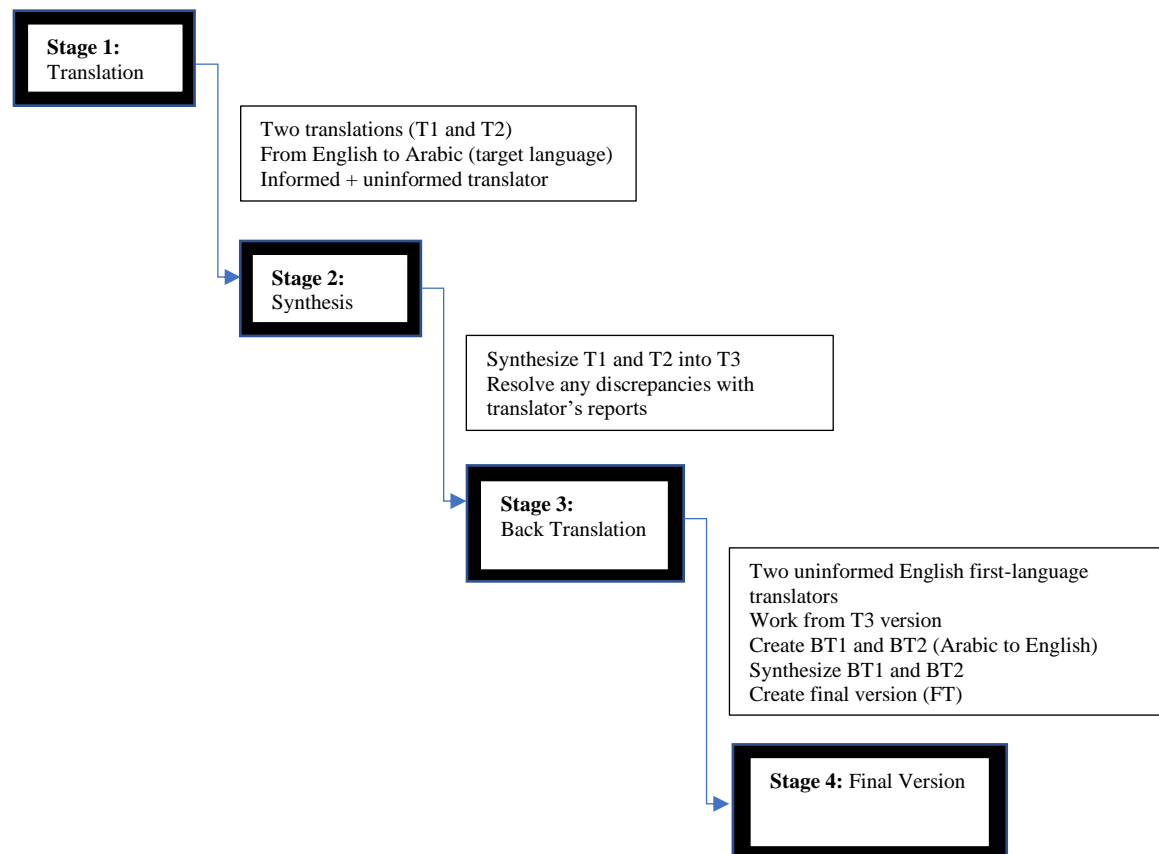
The Comprehensive Executive Function Inventory (CEFI; Goldstein & Naglieri, 2014) is an EF rating scale comprised of 100 items for individuals aged 5-18 years, with both parent and teacher rating forms. Parents and teachers are asked to rate behaviors observed during the last four weeks. The four EF sub scales assessed are: interference control, sustained attention, flexible switching and working memory. Standard scores < 90 indicate a weakness in executive function. The CEFI is highly correlated with similar and more widely used measures like the BRIEF (Gioia, Isquith, Guy, & Kenworthy, 2000) but it is more precisely normed than the BRIEF (Goldstein & Naglieri, 2014) and also captures the ‘sustained attention’ EF domain, unlike the BRIEF. The test has reported excellent internal reliability (reliability coefficient of .99) for the full scale of both informant groups (Goldstein & Naglieri, 2014). All scoring was computerized via the CEFI Scoring Software Program and the MHS Online Assessment Center (<https://www.mhsassessments.com>) which provides an automated procedure for addressing missing item scores. In addition to EF sub-scales, the CEFI provides standard scores for quality indicators: (a) consistency index (i.e., how consistent / inconsistent the rater’s responses were), (b) positive impression scale (i.e., the extent to which a rater creates an approving impression of the child), (c) negative impression scale (i.e., the extent to which a rater creates an unapproving impression of the child).

The CEFI is only available in English, and thus, an Arabic version was created with publisher approval – the procedure is detailed below. For the initial translation, two independent forward translations were made from English to Arabic by bilingual translators whose mother tongue is Arabic. One of the translators did not have knowledge of the CEFI items being quantified (as per publisher requirements) nor a developmental or clinical background. A written report was produced based on each translation (T1 and T2) with comments regarding challenges and reasoning for their choices recorded. Both translations were then combined into one common translation (T3). Any challenges resulting from synthesizing the translations and ways in which they were resolved were addressed in a separate written report.

The next stage involved two translators (with English as their mother tongue) who are blind to the English version back-translating the CEFI from Arabic to English to check validity (i.e., Arabic and English versions reflect the same item content). They too did not have knowledge of the concepts being quantified nor a developmental or clinical background to avoid biases. The outcomes of this collaboration were two backtranslations (BT1 and

BT2). Both translations were then synthesized into the final version (FT). Decisions pertaining to achieving equivalence between the English and Arabic versions in semantic equivalence, idiomatic equivalence, experiential equivalence, and conceptual equivalence (Beaton, Bombardier, Guillemin, & Ferraz, 2000) were achieved via this translation methodology (see Figure 2.0).

**Figure 2.0** CEFI Translation Methodology (from English to Arabic)



Adapted from (Beaton et al., 2000)

#### **D. Properties and procedure: Receptive and expressive language**

*Receptive language.* I selected the Peabody Picture Vocabulary Test-4 (PPVT-4) (Dunn & Dunn, 2007), a standardized measure of one-word vocabulary, as my measure of receptive vocabulary. A total of 228 items are divided into 19 sets, with each set displaying 12 items organized in ascending difficulty. There is a training page according to each age group, followed by the respective start page in the easel. Establishing a basal set (i.e., a set where a child makes 0 to 1 errors only) is the first goal. Children are presented with four pictures on

one page of the easel and they are required to select one picture (either point or vocalize the letter corresponding to the picture) that matches the word they heard. Once a child makes 8 errors, a ceiling set is then established. 0 points are granted for incorrect responses and 1 point is granted for a correct response. The total raw score is computed by subtracting the number of errors made from the last item on the ceiling set (i.e., if the child reached item 58 and made a total of 12 errors, then, they would have a raw score of 46).



**Figure 2.1** Receptive Vocabulary; Peabody Picture Vocabulary Test-4 (PPVT-4) (children must select one out of four displayed images)

The task was shortlisted as it met particularly key criteria. First, it takes an average of 15 minutes to administer, providing a relatively short administration time. Second, the test has strong psychometric properties for test-retest reliability (reliability coefficient  $> .90$ ) (Dunn & Dunn, 2007). Third, the task has established norms for ages 2-90 years, therefore it is suitable for use with participants of different age groups and intellectual functioning abilities. Fourth, the PPVT-4 has been widely used across a number of research fields, with autistic (see Krasileva, Sanders, & Bal, 2017 for a review) and bilingual typically developing children (e.g., Goriot et al., 2018; Wood, Stockholm, Cearley, & Sheffield-Anderson, 2015).

With respect to task limitations, even though children are encouraged to make a response only when they know the meaning of a word or think they know the meaning of a word (if they have no idea what a word means they are encouraged to say “next” or “I don’t know”), this instrument allows for responses that are guesses. Due to the multiple choice nature of the response options, children can guess, and there is a one in four chance of a correct guess.

The PPVT-4 is not available in Arabic. At the beginning of the study, I undertook an extensive search for an Arabic version of the Peabody Picture Vocabulary Test. First, I

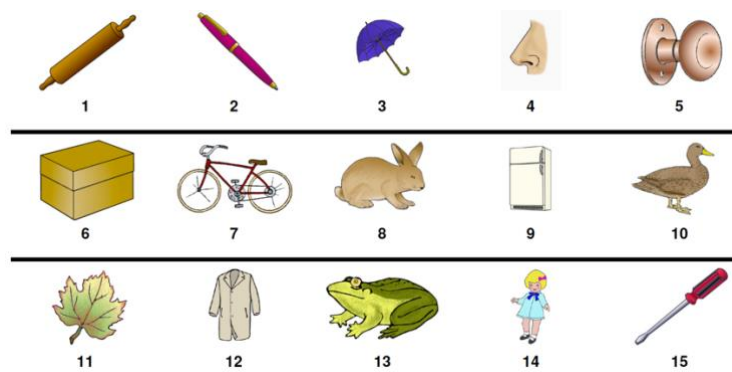
contacted the publisher who confirmed there is no Arabic version to this test. Second, I located two publications by Abu Allam and Hadi (1998) and Khammash (1995) which published the Arabic version of the PPVT, but was unable to locate or secure a copy of the test. I then managed to locate another task, based on the British Picture Vocabulary Test (BPVT), namely the Arabic Picture Vocabulary Test (APVT) developed by Shaalan (2010) in Qatar. This test is not standardized, but shows good correlations with the BPVT and has reportedly high internal reliability (reliability coefficient of .82) (Shaalan, 2017). It was administered to 107 children aged 4-9 years in Shaalan's study, and therefore, which overlaps with the target age range for this project.

Just like the PPVT-4, it is a measure of one-word vocabulary with a list of 228 items grouped into 19 sets, each displaying 12 items organized in increasing difficulty. The booklet has start pages but no age groups assigned to the pages or items (everyone starts with the same word). The following were identical to the PPVT-4: task procedure, procedure for establishing basal and ceiling sets, and scoring.

There were two limitations to using this task. First, this instrument was developed for Gulf-Arabic speaking children (this refers to Arabic dialects spoken in the United Arab Emirates, the Eastern Province of Saudi Arabia, Kuwait, Qatar, Yemen, and Bahrain). It does not cater to the dialects spoken by other Middle Eastern countries (i.e., Egypt, Jordan, Lebanon, Syria, Morocco, Tunisia, Iraq, etc.). In cases where a child participant was non-Gulf-Arabic speaking, the words I pronounced were in Modern Standard Arabic (also known as Modern Written Arabic) or in the respective dialect of the child. Dialects serve day-to-day social situations, whereas Modern Standard Arabic is generally used in formal verbal or written situations (i.e., television and radio programs). Most children across the Middle East are exposed to Modern Standard Arabic as part of their schooling, and via cartoon programs as well. A Modern Standard Arabic translation of the test was shared by the author, and an Egyptian-Arabic translation was created by myself (a native Egyptian-Arabic speaker) and shared with the author for reference. When a non-Gulf-Arabic speaking child did not seem to recognize the word in Modern Standard Arabic, I (being familiar with several Middle Eastern dialects myself) pronounced the word in the child's native dialect (with assistance from parents when needed). Second, just like the PPVT-4, this instrument allows for responses that are guesses due to the multiple choice nature of the response options.

*Expressive language.* Participants' proficiency in English and in Arabic (expressive vocabulary) was evaluated by a test of productive vocabulary, the Picture Naming Test (PNT; Kharkhurin, 2008). Language proficiency was assessed by the accuracy of children's verbal

responses to 120 paper-administered pictures of simple objects. This test was shown to strongly correlate with bilingual participants' self-ratings of language skills (Kharkhurin, 2008), and is similar to the Boston Naming Test (Kaplan, Goodglass & Weintraub, 1983). 1 point was awarded for correct responses and 0 for incorrect responses, with the maximum number of points being 120.



**Figure 2.2** Expressive Vocabulary; Picture Naming Task (PNT) (1-15 out of 120 simple images)

The task was shortlisted as it met particularly key criteria. First, it takes an average of 15 minutes to complete, providing a relatively short test time for participants. Second, the test is published in both English and Arabic. With respect to task limitations, the Arabic version of the test is in Modern Standard Arabic. It is not available in dialect-form. Children would often express some words in their local dialect, and while I had a particularly well-developed understanding of the children's respective dialects (especially given the simplicity of the images presented – basic words) and scored accordingly, translation checks were obtained from parents and teachers when needed.

### **E. Properties and procedure: Language history and use**

For language history and use, the Child Language Experience and Proficiency Questionnaire LEAP-Q (Marian et al., 2007) gathers information from participating families on home language environment history. Relevant language variables include current language exposure in both languages (indicated by the percentage of time a child currently on average hears their first and second language – at home and/or school), current active speaking in each of the two languages (indicated by the percentage of time a child currently on average speaks their first and second language – at home and/or school), and language proficiency

(indicated by a 10-point scale from 0 ‘none’ to 10 ‘perfect’) in each language. The instrument reportedly good reliability (reliability coefficient  $> .70$ ) (Marian et al., 2007), is available in more than 20 languages (Arabic included), at no cost, and takes 20 minutes on average to complete.

The Bilingual Switching Questionnaire (BSWQ) (Rodriguez-Fornells et al., 2012) was adapted from a self-report to a parent-report in order to record different types of switching behaviors in children. Parents rate 12 statements on switching behavior, on a 5-point scale from ‘never’ to ‘always’. These were coded as: 0 for ‘never’, 1 for ‘very infrequently’, 2 for ‘occasionally’, 3 for ‘frequently’ and 4 for ‘always’. Four switching behavior scales are captured. ‘L1-switch’ measures the child’s tendency to switch from their second language to their first, while ‘L2-switch’ measures the child’s tendency to switch from their first language (L1) to their second (L2). ‘Contextual switch’ measures the frequency of switching that takes place in a particular context. ‘Unintended switch’ measures the lack of awareness for language switches. For each child, the scores on each of the four switching behaviors were calculated by raw addition of the corresponding item scores. Very good reliability (reliability coefficient  $.74 - .92$ ) has been reported for this instrument (Rodriguez-Fornells et al., 2012). The BSWQ takes less than five minutes to complete, and is readily available at no cost.

## **F. Properties and procedure: Autism profile**

The Social Responsiveness Scale-2 (SRS-2) (Constantino & Gruber, 2012) is a 65-item rating scale associated with identifying social behaviors in autism. Each item is rated on a 4-point scale: 1; ‘not true’, 2; ‘sometimes true’, 3; ‘often true’, 4; ‘almost always true’. The school-age form (4-18 years) was administered to teachers (the scale takes 15-20 minutes on average to complete). Results are reported as *T*-scores (mild to clinically significant) for two sub-scales: social communication impairment (SCI) (marked by ‘social awareness’ (8 items) + ‘social cognition’ (12 items) + ‘social communication’ (22 items) + ‘social motivation’ (11 items)) and restricted interests and repetitive behaviors (RRBs) (marked by stereotypes and circumscribed, using 12 items). The total SRS-2 score is marked by SCI + RRBs.

‘Social awareness’ refers to the ability to recognize social cues of others, whereas ‘Social communication’ is associated with shared communication in social contexts. On the other hand, we have ‘Social motivation’ which refers to the degree of individual motivation to socially interact with others. Across the aforementioned two sub-scales, *T*-scores  $\geq 76$



indicate a high range of clinically significant difficulties in social functioning. *T*-scores of 66 and 75 are considered moderate, referring to some clinically significant deficits in the social domain. *T*-scores that range from 60 to 65 indicate mild to moderate social deficits. Finally, *T*-scores  $\leq 59$  are indicative of a lack of social deficits.

High internal consistency is reported for SRS-2 (reliability coefficient of .95). Furthermore, comparisons between TD and clinical groups yielded large effect sizes, suggesting high validity (Constantino & Gruber, 2012).

With respect to task limitations, while the Arabic version of the instrument was purchased from the publisher, there is a lack of publications on the psychometric properties of this instrument in an Arabic-speaking population. Therefore, existing norm scores for the SRS-2 could not be extended to a sample based in the Arab world. In fact, investigations of the German version of the SRS revealed lower scores than US norms (Bolte et al., 2008).

### **G. Properties and procedure: Intellectual functioning**

The Colored Raven's Progressive Matrices (CPM) (Raven & Court, 1998) was selected to measure non-verbal IQ in my sample of TD and autistic children. This norm-referenced measure is administered to one person at a time, and contains 36 patterns spread across three sets: set A (12 patterns), set B (12 patterns) and set Ab (in between A and B) (12 patterns). On each pattern, children are asked to identify the missing element that completes the pattern. This draws on the ability to distinguish perceptual associations and reason by analogy. Patterns are presented in the form of a matrix (e.g., 2x2, 6x6), giving the test its name. The number of correct scores (standard raw scores) is converted to percentile scores (as per the participant's age group) and can be matched to an IQ grade or level.

Several factors point to the suitability of CPM for the current work. First, it does not require verbal responses and has minimal verbal instructions, making it particularly well-suited for autistic children. Second, the Raven's has been reported to be one of the most extensively used tools to assess nonverbal intellectual ability for matching in research with autistic participants (Motttron, 2004). Third, the significant correlation between autistic participants and TD participants' results on each item of the Ravens progressive matrices (RPM) (Dawson et al., 2007; Morsanyi & Holyoak, 2010) could suggest that RPM assesses general IQ in autistic populations to the same extent as it does in TD populations. Fourth, there are reported norms for both Raven Matrices and its variants, in 16 Arab countries (Fasfous et al., 2017), a key point for the current study since data are collected from an Arab

Country with a sample comprised of predominantly Arab nationals. Fifth, it offers a relatively short administration time (15-20 minutes) and is suitable for use with my target age group. Finally, the CPM was readily available to me at no cost given the manual, book, and score sheets were shared by my university department.

## **H. Shortlisted executive functions measures**

The following 8 EF measures were carried forward for piloting:

- (a) Flexible switching (2 tasks): the Dimensional Change Card Sort Task (DCCS) and the Switch Task.
- (b) Working Memory (2 tasks): the Self Ordered Pointing Task (SOPT) and Frog Matrices Task (FMT).
- (c) Interference Control (2 tasks): the Flanker Task and the Simon Task.
- (d) Sustained Attention (2 tasks): the Psychomotor Vigilance Task (PVT) and the Sustained Attention Response Task (SART) of the TEA-CH2.

## **6. Pilot study**

### **A. Aims**

In order to determine the suitability of this set of measures for the final study protocol, a pilot study was run in Edinburgh, United Kingdom. Participants were bilingual and monolingual autistic children (five participants), and one TD sibling. The purpose of the pilot was to examine feasibility and acceptability, and to inform the protocol for a larger scale study to be carried out in the UAE.

In particular, the goal of the pilot was to determine the ideal task battery. The section above describes a list of measures selected to evaluate the language and EF profiles of autistic and TD children in the UAE. For more convincing evidence of a bilingual advantage that can be attributed to a specific component of EF, Paap et al. (2015) recommended using two converging tasks to measure each EF construct under study. This is because experimenting with multiple measures for the same EF construct can allow for evaluation of the extent to which performance patterns are consistent, so that if an advantage is found for one task but not the other(s), one can conclude that the advantage here is in the non-EF variance rather than an EF advantage. Following this recommendation, two tasks were shortlisted per EF construct and administered during the pilot study.

## **B. Participants**

I recruited potential participants via a research database, word-of-mouth referrals and social media adverts. Interested families were contacted by email and forwarded a parent information sheet and a consent form. Following confirmation of interest, I telephoned the family to discuss the study further, to answer any questions, and to confirm eligibility. Data collection took place at a home visit, which started with taking informed consent from the parent and confirming assent with the child. The procedure for this was a verbal explanation of the study, after which the child could circle a face (happy or sad) to mark their decision to participate or not.

## **C. Design**

The pilot is an observational study made up of a few participants aimed at examining feasibility and acceptability of the aforementioned shortlisted measures to inform the battery of measures to be used in the main study.

## **D. Materials**

All tasks were computerized, ran on E-Prime 2.0 and visual basic software – with the exception of Raven's CPM which was paper-based, and administered on a touchscreen laptop (Toshiba Portege m780-10v). A research diary was kept throughout the pilot study phase. The aim for this diary during the pilot phase was to record details of researcher methodological observations during and immediately after the experiment. These detailed notes were recorded to learn from the pilot phase and adapt the main study protocol accordingly.

Examples of research notes include comments on: 1) signs of fatigue as a result of administering 8 EF (2 tasks for each of the 4 EF domains) cognitively demanding tasks in one session, 2) total number of breaks between EF tests, 3) total time it took for all 8 tests of EF, 4) adjustments to test duration and/or increasing practice blocks, 5) tools to record responses – any issues for participating children using the keyboard to mark responses, 6) figuring out the order of the tasks as per task demand / difficulty / length, 7) ways to actively engage participants to complete the tasks, particularly autistic participants, and 8) observations related to the research setting – distractions, handling parent feedback, etc.

## **E. Procedure**

Participants were visited at home and were administered the IQ test first (following child consent) followed by the direct EF tests. The Raven's CPM task was always administered first. The rest of the tasks were not administered in any particular order as children varied in their motivations, preferences and moods. Therefore, it was a case by case decision with respect to task order administration.

Generally speaking, with TD populations, the EF battery (in the order of flexible switching, interference control, working memory and sustained attention) preceded direct language measures (in the order of PPVT, PNT English and Arabic, APVT). Every attempt was made to administer the flexible switching tasks first (as an ice breaker task – it offered me a good opportunity to engage with the participant throughout the task), followed by the interference control tasks (fastest test), and working memory, ending with the sustained attention tasks (a rather fun ending for those with a competitive nature as the RT score appears on the screen for every trial). The diary was filled out for every participant within 12-24 hours of completing the research visit.

## **F. Results**

It was clear from the pilot that children could not tolerate the length of the testing session required to complete my full battery of assessments. Therefore, one measure was eliminated for each of the selected EF domains.

*Flexible switching.* Compared to the Switch Task, the DCCS task is widely used in the study of flexible switching with autistic participants (i.e., Dichter et al., 2010; Faja & Dawson, 2014; Gonzalez-Barrero & Nadig, 2017). In addition, the children found the DCCS much more enjoyable to play than the Switch Task. Guided by these insights and task characteristics, a decision was made to eliminate the Switch Task and select the DCCS Task as the study's direct measure of flexible switching. With respect to DCCS task limitations, some children tapped the touchscreen display incorrectly on some trials (e.g., tapping twice, two-finger tapping) which prevented the dragging motion to sort the respective images. This sometimes led to multiple drags which increase reaction times. Some children even dragged the cards to be sorted around the screen to 'play' with it before sorting. While they were immediately prompted to sort the picture as quickly as possible, this nevertheless led to longer reaction times.

*Interference control.* When piloting inhibition tasks, the Fish Flanker Task proved to be somewhat effortless for all participants. Even when trials were increased, the task seemed

to exert minimal EF demands on the children. Most children described this task as ‘boring’ and, while attempting the task, often questioned when it would be over. In contrast, the participants found the Simon Task cognitively demanding. Part of this, which could be considered a limitation of the task, relates to working memory demands: to be able to perform the task, children had to remember the correct key-color combination throughout. This could have likely increased EF tax, especially for autistic participants. Some even remarked that the test was ‘too fast’ on some trials. While the test is widely used in TD populations, it is not necessarily adapted to accommodate individuals with different processing abilities (another limitation of this task). However, several findings highlighted earlier in the literature suggest that a bilingual advantage is more likely to emerge in situations that utilize higher executive demands. Guided by theory, evidence-based findings from bilingualism literature, and children’s responses during the pilot phase, a decision was made to eliminate the Fish Flanker Task and select the Simon Task as the study’s direct measure of interference control.

*Sustained attention.* When piloting sustained attention tasks, the SART (TEA-Ch2) proved to be exceedingly difficult for all participants, but even more so for autistic participants (the majority of the pilot sample). The children found the speed with which the stimuli appeared and disappeared to be too fast to process. This was evident by slower responses using the keyboard which led to several missed trials, and frustrated facial reactions. In contrast, the children found the PVT an exciting game to play and responded competitively to the task as they were keeping track of their ‘best reaction time’. The test was easy enough to navigate but simultaneously exerts sustained attention demands. Guided by children’s feedback and task characteristics, a decision was made to eliminate the SART and select the PVT as the study’s direct measure of sustained attention. With respect to task limitations, PVT normative data are limited, making clinical between-subject comparisons difficult.

*Working memory.* Unlike the FMT, the SOPT has been established for use with autistic children (Joseph et al., 2005). Furthermore, in contrast to the FMT, the SOPT correlates with other measures of working memory and learning (some correlations are modest) (Bryan & Luszcz, 2001; Ross et al., 2007; Roth & Baribeau, 1996). Moreover, selecting the SOPT as the study’s measure of working memory would allow me to investigate performance differences (if any) within groups on the verbal (object) versus the non-verbal (abstract) condition. Autistic children have been reported to perform significantly lower on the verbal version of the SOPT relative to the non-verbal version (Joseph et al., 2005).

Therefore, it would be insightful to investigate the case of verbal vs. non-verbal SOPT performance further. Guided by literature findings and task characteristics, a decision was made to eliminate the FMT and select the SOPT as the study's measure of working memory.

It is interesting to note an observation made during the pilot study phase; some children were making up words (verbal codes) as a strategy for remembering the abstract images presented to them. For instance, a child would say: "I'm going to name this picture dangerous alien because that's exactly what it looks like". Furthermore, in the abstract condition, one or two autistic children were selecting the same image repeatedly because that specific pattern was visually appealing to them. In this case, they were offered a print out of their favorite picture to hang up in exchange for making correct responses; selecting each picture only once.

With respect to task limitations, one limitation is the probability of a correct response due to guessing or random responses. Some children, as a result of either excitement or frustration with the task, selected pictures randomly at a certain point, at which point, they were reminded to take their time, look at the pictures, and touch a new picture each time. A second limitation relates to the psychometric properties of the SOPT (both the abstract and the object version); there is a lack of information on the psychometric properties of the SOPT outcome variables (i.e., monitoring errors, repetitive errors, span errors) in large and diverse populations made up of typical and atypical groups.

## **7. Discussion**

The main adjustment from the pilot study to the main study is the elimination of the 'two tasks per direct EF' decision which resulted in the selection of one direct EF task per EF construct. Below is a table of the finalized protocol, which summarizes all the instruments used in this PhD, what they assess, their type, and finally, their duration.

## **8. Finalized battery of executive functions measures**

The following 4 EF measures were selected from the pilot to inform the main study:

- (a) Flexible switching (1 task): the Dimensional Change Card Sort Task (DCCS).
- (b) Working Memory (1 tasks): the Self Ordered Pointing Task (SOPT).
- (c) Interference Control (1 tasks): the Simon Task
- (d) Sustained Attention (1 task): the Psychomotor Vigilance Task (PVT).

## **9. Finalized procedure**

Recruitment calls were circulated via schools, centers, psychology mailing lists, Facebook, twitter, radio channels, WhatsApp, and autism-related conferences and workshops. Direct assessments took place at appointments held across various locations: mainstream schools, autism centers, families' homes, or local cafes with a research-friendly environment (quiet and with private table space).

Testing location was determined by families of eligible children. Children were seen between 1-3 times (depending on the participant) to complete their data collection. Raven's CPM was always administered first whereas the computerized tasks were not administered in any particular order as participants varied in their motivations, preferences and moods. However, every attempt was made to administer the flexible switching task first, as an ice breaker task – it offered me a good opportunity to engage with the participant throughout the task. This was followed by interference control and working memory tasks, ending with the sustained attention task. Language screening assessments were administered either before or after the computerized tasks, depending on the participant. Determination of language status (bilingual or monolingual) took place after the research session completion, upon securing both parent and direct ratings of language and calculating respective scores based on direct and parent-reported measures of language.

There were three routes to collect consent and survey data. The first route involved the circulation of these documents to families of eligible children by staff at participating organizations (i.e., schools, autism centers). In-charge staff either handed parents the documents in person (i.e., at child pick-up or drop-off times) or placed the documents in the child's backpack with a note requesting the return of these documents by a certain date. Follow up reminders to families who did not return the documents by the requested date were taken up by in-charge staff members or myself (if I had the family's contact number, I would follow up directly). The second route involved the circulation of these documents (in Microsoft Word) to families of eligible children (via in-charge staff or myself) by email. Documents were filled out and returned by email, and I sent follow up email reminders when needed. The third route involved families filling out these documents on the day of their child's appointment. Documents were either collected by the end of the appointment or I returned later to pick up these documents from families' homes (at an agreed time) if they were not fully completed. The same routes were in place to collect teacher survey data,

except, in the third route, I would pick up the forms from teachers' schools and centers and not their residences.

For direct Arabic language assessments of expressive and receptive vocabulary, parents and teachers were sometimes asked to confirm translations of words from a child's local Arabic dialect to Modern Standard Arabic so that the word could be scored as 'correct' or 'incorrect'. This was due to the fact that the Arabic language tests used were not available in all dialects. While I was familiar with the children's local dialects, the inclusion of parent or teacher feedback provided concordance with my scoring for certain words.



## Chapter 3: The impact of bilingualism on the executive functions of autistic children: A study of English-Arabic children.

This chapter has been submitted for publication to the academic journal ‘Autism Research’ with the following citation: **Sharaan, S.**, Fletcher-Watson, S., & MacPherson, S.E. (2020). The Impact of Bilingualism on the Executive Functions of Autistic Children: A Study of English-Arabic Children. Below is the full text of the submitted manuscript.

**Abstract:** There is evidence to suggest that certain executive functions are impaired in autistic children, contributing to many daily challenges. Regular use of two languages has the potential to positively influence executive functions, though evidence is mixed. Little is known about the impact of bilingualism on the executive functions of autistic children, with only a handful of studies published worldwide to date. This study investigated the impact of bilingualism on sustained attention, interference control, flexible switching and working memory, in Arabic-English autistic children ( $n = 27$ ) and their typically developing peers ( $n = 66$ ), aged 5 to 12 years old. Groups were matched on age, non-verbal IQ and socioeconomic status, and completed a battery of computerized tests. Results showed an advantage for bilingual autistic children relative to their monolingual peers in sustained attention, and equivalent performance between bilingual and monolingual autistic children on all other executive functions. There were no generalized positive effects of bilingualism, and typically-developing children performed better than autistic children on all measures. The findings indicate that bilingualism does not negatively impact the executive function skills of autistic children, and that it might mitigate difficulties in sustained attention.

**Keywords:** Dual Language, Second Language Exposure, Autism, Cognition

### Introduction

Executive functions abilities play a significant role in various educational (Allan, Hume, Allan, Farrington, & Lonigan, 2014; Dekker, Ziermans, Spruijt, & Swaab, 2017) and social outcomes (Hughes, White, Sharpen, & Dunn, 2000; Murphy, Shepard, Eisenberg, & Fabes,

2004) for typically developing children, also having a broader impact on quality of life (Tangney, Baumeister, & Boone, 2004). There is evidence to suggest that executive function (EF) skills are impaired in autistic children (Demetriou et al., 2017; Lai et al., 2017), though the profile of EF in autism is characterized by significant heterogeneity (Geurts, Sinzig, Booth, & Happé, 2014; Pellicano, 2010). Executive functions have been proposed to make a pivotal contribution to key features of autism such as repetitive behaviors (Mostert-Kerckhoffs, Staal, Houben, & Jonge, 2015). They may also influence communication and social interaction challenges (Leung, Vogan, Powell, Anagnostou, & Taylor, 2016) and have a negative impact on quality of life (Vries & Geurts, 2015). Therefore, there is clear evidence of individual differences between autistic individuals in their EF profiles, but the factors that influence EF development and outcomes in autism are still poorly understood (Demetriou et al., 2017). One candidate factor could be bilingual exposure.

Bilingualism is a skill shared by more than half of the world's population (Grosjean, 2010). A range of markers of bilingualism have been related to enhanced EF development in typically developing children, including earlier age of acquisition of languages (Kapa & Colombo, 2013), higher proficiency in languages (Niharika & Ramesh Kumar, 2013), and frequency of switching between languages (Prior & Gollan, 2011). The impact of bilingualism on EFs in typically developing children remains hotly debated, with evidence for (Barac, Bialystok, Castro, & Sanchez, 2014; Bialystok, 2001) and against (de Bruin, Treccani, & Della Sala, 2015; Dick et al., 2019; Paap & Greenberg, 2013) a bilingual advantage. A full account of the complexities and challenges within the existing literature are beyond the scope of this paper, but see Paap and Greenberg (2013) and de Bruin, Treccani, and Della Sala (2015) for important discussions of the relevant issues.

A prominent explanatory framework for the theoretical relationship between bilingualism and EF is the adaptive control hypothesis (Green & Abutalebi, 2013). This model argues that language context is a key determinant of the impact of bilingualism on EF. In a single language context, one language is spoken in one environment while the other language is spoken in another distinct environment (e.g., English at school and Arabic at home). No switching between the two languages is required. In a dual language context, both languages are spoken within the same environment, resulting in frequent switching. In a dense-switching language context, speakers alternate between the two languages within single statements, or adapt words from one language to integrate with another. The adaptive control hypothesis claims that a dual-language context places the highest demand on the EF skills of sustained attention, inhibitory control, and switching relative to other contexts.

In support of this, there is evidence from typically developing children that the frequency with which early bilinguals (defined as those who start to use their L2 before the age of 7; Lenneberg, 1967) switch between their languages on a daily basis is a significant predictor of flexible switching error rates on a number-letter task (Soveri, Rodriguez-Fornells, & Laine, 2011). It has also been demonstrated that early bilinguals who reported frequently switching between their languages had a task switching advantage on a color-shape task, while bilinguals who reported less frequent language switching performed equivalently, compared with monolingual peers (Prior & Gollan, 2011). Likewise, there is evidence of an association between interference control skills (e.g., the Flanker task) and language switching abilities in balanced bilinguals (Verreyt, Woumans, Vandelandotte, Szmalec, & Duyck, 2016). These findings support the theoretical relationship between language switching and key EF domains in bilingual individuals.

Disadvantages in EF domains for bilingual typically developing (Dick et al., 2019) and bilingual autistic (Gonzalez-Barrero & Nadig, 2017) children are very rarely in evidence. Despite this, parents (Hampton, Rabagliati, Sorace, & Fletcher-Watson, 2017) and practitioners (Moore & Pérez-Méndez, 2006) have concerns about raising autistic children speaking more than one language. Such deficit views of bilingualism may negatively impact autistic children's linguistic, social and cultural development (Uljarević, Katsos, Hudry, & Gibson, 2016; Yu, 2013). Moreover, there is a small but growing body of evidence showing that bilingualism does not have a detrimental impact on language outcomes for autistic children (Hambly & Fombonne, 2012; Uljarević et al., 2016).

In the EF domain, evidence remains sparse, but one study found no differences between autistic children who were exposed to a second language or not, on parent-reported EF outcomes (assessing problem solving, attentional control, behavioral control and emotional control) (Iarocci, Hutchison, & O'Toole, 2017). However, in this study, despite this lack of statistical differences in mean EF ratings between the language exposure groups, autistic children who had been exposed to a second language were less likely to have EF ratings in the clinically significant range of concern. In another study, autistic children exposed to a second language > 10% of the time had reduced parent-reported difficulties compared with autistic monolinguals on inhibitory self-control and flexible switching (Ratto, Potvin, Pallathra, Saldana, & Kenworthy, 2020).

Using directly-assessed measures of EF, one study reported bilingual autistic children performed similarly to their monolingual peers on EF outcomes using three tasks assessing inhibitory control (Stroop task, Simon task, Go/No-Go) and one task assessing flexible

switching (Wisconsin Card Sorting Task) (Li, Oi, Gondo, & Matsui, 2017). Two studies found tentative evidence of a bilingual advantage for autistic children relative to their monolingual peers using direct tasks assessing inhibitory control (Li et al., 2017) and flexible switching (Gonzalez-Barrero & Nadig, 2017) domains. However, in each case, only a single variable revealed a bilingual advantage out of two candidate outcome variables, so it is unclear whether these effects are robust. Furthermore, in the latter study, when using a parent report measure, there were no significant differences between bilingual and monolingual autistic children on flexible switching scores.

Combined, these quantitative studies in the language and EF domain support the idea that bilingualism is not detrimental to autistic children's development. In addition, there is qualitative evidence that bilingual autistic children educated in multilingual environments view bilingualism as an enriching aspect of their identities and linguistic repertoires (Howard, Katsos, & Gibson, 2019).

The current study investigates the impact of bilingualism on EF skills, focusing on domains relevant to the adaptive control hypothesis – sustained attention, flexible switching, and interference control – but also measuring working memory as an active control condition which is not hypothesized to be influenced by bilingual exposure. The study takes place in a dual-language environment (United Arab Emirates), presenting an ideal opportunity to examine the predictions of the Adaptive Control Hypothesis. According to this model, a dual-language context is most likely to result in advantages for the aforementioned EF domains. Therefore, the current work tests this hypothesis in relation to Arabic-English bilinguals.

The United Arab Emirate's leading language is Arabic and it is one of the world's top five most spoken languages, having over 240 million native speakers (Adams & Fleck, 2015). English is widely accepted as the lingua franca as an estimated 90% of the population is migrant (non-nationals) (De Bel-Air, 2015). In addition to the dual Arabic-English language context, a triglossic context exists with three different varieties or dialects of spoken Arabic; Classical Arabic (i.e., Arabic used in the Quran and literary works), Modern Standard Arabic (i.e., Arabic used in formal communications), and Colloquial Arabic (i.e., Arabic used in dialects and everyday language) (Sabbah, 2015). In his investigation of language in education in the United Arab Emirates, Al Sharhan (2007) illustrated that Emirati children are required to develop all three varieties as part of their education.

Therefore, based on the theoretical model under investigation, we pose the following question: what is the impact of bilingualism on the EF domains most relevant to a dual-language context, in a group of school-aged autistic children? We hypothesize the following:

First, we predict that bilingual children will outperform monolingual children on measures of flexible switching, sustained attention and interference control. We predict no influence of bilingualism on working memory. In addition, we will explore interactions between diagnostic status and bilingualism in their effect on EF scores, but based on the current literature, make no firm predictions about EF performance between autistic bilinguals and typically developing bilinguals.

## **Methods**

### *Participants*

Ninety-three children aged between 5 and 12 years were recruited into the study ( $M = 9.16$  years,  $SD = 1.98$  years). Monolingual children spoke either English ( $n = 39$ ) or Arabic ( $n = 3$ ), and bilingual children spoke both English and Arabic. All bilinguals spent significant amounts of time in dual-language switching environments, where both Arabic and English were actively used within one context (i.e., school / educational context, and sometimes also the home context) but with different individuals.

The inclusion criterion for autistic children was a formal diagnosis of autism based on DSM-IV or DSM-V criteria, confirmed by the referring organizations (e.g., autism center) or by a parent. Non-verbal IQ and language screening tools were administered to further determine eligibility and language status. All children had a non-verbal IQ score of ‘intellectually average’ or above as screened by the Raven’s Colored Progressive Matrices (CPM) (Raven & Court, 1998b). There were no uncorrected visual deficits, hearing deficits, cognitive disabilities and co-morbidities (e.g., ADHD). Language status (bilingual or monolingual) was screened based on a combination of parent language report and direct expressive and receptive vocabulary measures. The Child Language Experience and Proficiency Questionnaire (Marian, Blumenfeld, & Kaushanskaya, 2007) (collecting language history, current exposure, current use and proficiency data) was administered to parents, in either Arabic or English. Expressive vocabulary was measured with the Picture Naming Test (Kharkhurin, 2008) in Arabic and/or English. Receptive vocabulary was measured with the Peabody Picture Vocabulary Test, 4<sup>th</sup> ed. in English (Dunn & Dunn, 2007) and the Arabic Picture Vocabulary Test (Shaalán, 2010) in Arabic.

Determination of a child’s bilingual status was based on a combination of the following indicators: (a) > 20% of current exposure to each of the two languages at home or school, according to parent report, (b) > 20% of current active speaking in each of the two

languages at home or school, according to parent report, (c) > 20% proficiency score (24 correct responses out of a possible total of 120) in each of the two languages according to the Picture Naming Test, rated by the researcher.

Language proficiency was assessed based on the accuracy of participants' written responses to the objects in the Picture Naming Test. Determination of a child's monolingual status was based on a combination of the following indicators: (a) had not been exposed to a language other than Arabic (or English if their first language was English) for more than 20% of their lifetime, (b) if exposed to a second language, < 20% of current active speaking at home or school, according to parent report, (c) if exposed to a second language, < 20% proficiency score according to the Picture Naming Test, rated by the researcher.

Ethical approvals were obtained from the University of Edinburgh (School of Philosophy, Psychology and Language Sciences, Application 102-1718/2), the Abu Dhabi Department of Education and Knowledge, and the UAE Ministry of Community Development. All parents and participants gave informed consent.

Details of participant characteristics are presented in Table 4. A series of one-way analysis of variance (ANOVA) confirmed no significant differences between the monolingual and bilingual autistic and typically developing (TD) groups on the following six characteristics: chronological age ( $p = 0.486$ ); non-verbal IQ ( $p = 0.454$ ); maternal education level ( $p = 0.140$ ); maternal continuous years of education ( $p = 0.663$ ); paternal education level ( $p = 0.095$ ); and paternal continuous years of education ( $p = 0.230$ ).

**Table 4.** Participant demographics by group: Directly-assessed EF

	Monolingual Autistic (N=10) M (SD)	Monolingual TD (N=32) M (SD)	Bilingual Autistic (N=17) M (SD)	Bilingual TD (N=34) M (SD)
Participant age ( <i>months</i> )	99.11 (22.78)	111.03 (27.74)	115.56 (24.24)	110.50 (19.63)
Non-verbal IQ ( <i>scores</i> )	27.90 (3.75)	30.63 (4.31)	30.24 (3.52)	30.44 (3.59)
Paternal education level	5.88 (1.24)	6.40 (1.24)	5.20 (1.47)	6.26 (1.10)
Paternal education ( <i>years</i> )	17.13 (3.31)	18.10 (3.13)	16.20 (1.98)	17.53 (1.63)

Maternal education level	5.50 (1.77)	5.83 (1.26)	4.92 (1.16)	5.82 (0.86)
Maternal education ( <i>years</i> )	17.00 (3.33)	16.67 (1.53)	15.83 (1.52)	16.88 (1.06)
Receptive Vocab English	107.63 (38.77)	110.91 (26.94)	86.92 (23.98)	120.26 (34.93)
Receptive Vocab Arabic	-	-	50.45 (25.63)	71.16 (24.39)
Expressive Vocab English	88.40 (32.51)	110.94 (7.23)	74.87 (19.17)	100.48 (16.50)
Expressive Vocab Arabic	-	-	61.40 (22.73)	65.39 (19.20)
Autistic Symptomatology	69.80 (16.14)	-	67.91 (10.28)	-
Gender (M/F)	8/2	13/19	10/7	8/26

*Note.* Education level = 0 (none), 1 (less than high school), 2 (high school), 3 (professional training), 4 (partial college), 5 (college), 6 (some graduate), 7 (masters), 8 (doctorate); Autistic Symptomatology = as assessed by the Social Responsiveness Scale-2: 76 or higher (“severe deficits”), 66 to 75 (“moderate deficits”), 60 to 65 (“mild to moderate deficits”), 59 and below (“no deficits”); M = mean; SD = standard deviation; TD = typically developing; CPM = nonverbal IQ standard score from the Colored Progressive Matrices.

## Materials

Explicit, computerized measures of EF were selected to capture each EF domain of theoretical interest. We selected tasks that minimize cross-talk between underpinning domains (e.g., flexible switching tasks with minimal working memory demands).

*Flexible Switching.* A computerized dimensional change card sorting task (DCCS task) (Diamond, Carlson, & Beck, 2005) was administered. In the pre-switch phase, participants sort images based on their color (indicated by a rainbow cue at the top of the screen), with 5 out of 6 correct trials needed to pass. In the post-switch phase, participants sort images based on their shape (indicated by a shape cue at the top of the screen), with 5 out of 6 correct trials needed to pass. Finally, in the mixed condition color-shape game, participants sort images based on either shape or color (indicated by a rainbow or shape cue at the top of the screen), with 9 out of 12 correct trials needed to pass. For each trial, an image appears in the middle of the screen and participants sort the image by dragging it to a red truck or blue star (e.g., in color trials, a blue image should be dragged to the blue star). Participants complete 14 practice trials with feedback and must answer correctly at least 4 trials to move on to the experimental trials. Outcome variables include accuracy, switch costs

(i.e., the mean reaction time of the first two trials from the post-switch phase minus the mean reaction time of the last two trials from the pre-switch phase), as well as mean RTs in the pre-switch, post-switch, and mixed trials condition. The DCCS is reported to have good re-test reliability (Beck, Schaefer, Pang, & Carlson, 2011).

*Interference Control.* In the Simon Task (di Pellegrino, Ciaramelli, & Làdavas, 2007; Simon, 1969), participants are required to respond as quickly and as accurately as possible to a red or blue square presented on the computer screen by pressing the left button for blue squares and the right button for red squares, regardless of the square's position. For congruent trials, the position of the square and the response button match (e.g., a red square presented on the right) and for incongruent trials, the position of the square and the response button do not match (e.g., a blue square presented on the right). The task consists of 10 practice trials with feedback and 56 experimental trials without feedback. The main outcome measures are the mean congruent RT, the mean incongruent RT, and the Simon interference effect (i.e., mean incongruent RT / mean congruent RT). The Simon task is reported to have good re-test reliability (Wostmann et al., 2013).

*Sustained Attention.* In the Psychomotor Vigilance Task (PVT) (Lara, Madrid, & Correa, 2014), participants are asked to press the space bar as soon as a black circle starts to fill in red in a clockwise direction. Once participants respond, their RT is displayed on the screen. If a response is made too soon (i.e., pressing before the red starts to appear) or a response is not made (i.e., the entire circle is filled in red), feedback is given stating “too quick” or “too slow”. Participants perform 5 practice trials and then 88 experimental trials. Outcome measures include mean RT and the number of false starts (RT <100 ms). The PVT is reported to have high re-test reliability (Wilson, Dollman, Lushington, & Olds, 2010).

*Working Memory.* Object and abstract picture versions of the computerized Self-Ordered Pointing Task (SOPT) (Cragg & Nation, 2007; Macpherson, Phillips, & Della Sala, 2002) were administered. The SOPT assesses the ability to arrange, perform, and monitor a sequence of responses. In both versions, participants are presented with an array of black and white pictures of objects or abstract pictures. Participants were repeatedly presented with the array and instructed to choose one of the items in the array by touching the screen, each time choosing an item that has not been previously selected. Therefore, participants have to monitor their previous choices while they prepare each new response. The position of the items changes across presentations. Participants perform 3 trials containing 4 pictures each (i.e., practice trials), followed by 3 trials containing 6 pictures each, then 3 trials containing 8 pictures each, and finally, 3 trials containing 10 pictures each. For each trial, the array is



presented the same number of times as the set size (e.g., for a trial with 10 pictures, the array is presented 10 items). The outcome variables are SOPT mean errors for each set size. The SOPT is reported to have very good re-test reliability for total errors (Ross, Hanouskova, Giarla, Calhoun, & Tucker, 2007).

### *Procedure*

Participants were recruited with the cooperation of 22 institutions (e.g., autism centers), across three Emirates (Abu Dhabi, Dubai, Sharjah) between March 2018 and April 2019. Recruitment calls were circulated via schools, centers, research mailing lists, social media, and autism-related conferences and workshops. Participants were assessed individually over 1-3 sessions, depending on the participant. For bilinguals, tasks were administered according to each child's communicated language preference / dominance (English / Arabic). For the large majority of bilinguals, that language was English. Raven's Colored Progressive Matrices was always administered first to screen for non-verbal IQ (i.e., only children with a score of 'intellectually average' and above were eligible for participation).

The computerized tasks were not administered in any particular order as participants varied in their motivations, preferences and moods. Every attempt was made to administer the flexible switching task first, as it is more engaging, and makes participants feel relaxed and comfortable, followed by the interference control and working memory tasks, ending with the sustained attention tasks. Language screening assessments were administered either before or after the computerized tasks, depending on the participant. Determination of language status (bilingual or monolingual) took place after the research session completion, upon securing both parent and direct ratings of language and calculating respective scores.

### **Results**

Statistical analyses were performed in SPSS (24). The data were screened to ascertain if they were normally distributed and log10 transformations were applied if the data were skewed. For our continuous outcome variables, two-way analysis of variance (ANOVA) were conducted with diagnostic group (Autistic, TD) and language group (monolingual, bilingual) as between-subject factors. For our categorical variables, Fisher's exact tests were run, first examining diagnostic group effects, and then examining bilingualism. In cases where the assumption of normality was not met after the data were transformed, we used non-

parametric Mann Whitney tests. The p-value was Bonferroni adjusted to avoid Type 1 errors (0.05 / the number of outcome variables per EF task). The adjusted alpha level for significance is presented for each outcome variable. Means and standard deviations on all EF outcomes are provided in Table 5.

**Table 5.** Results from directly-assessed EF measures by group

	Monolingual Autistic M (SD)	Monolingual TD M (SD)	Bilingual Autistic M (SD)	Bilingual TD M (SD)
<i>DCCS</i>	( <i>n</i> = 9)	( <i>n</i> = 31)	( <i>n</i> = 14)	( <i>n</i> = 31)
<b>Task accuracy</b>				
Pre-switch <sup>a</sup> (6 trials)	5.56 (.72)	5.94 (.25)	5.57 (.75)	5.97 (.18)
Post-switch <sup>a</sup> (6 trials)	5.33 (.86)	5.77 (.49)	5.00 (.67)	5.58 (.62)
Mixed condition <sup>a</sup> (12 trials)	9.78 (2.22)	11.35 (.91)	9.21 (2.22)	11.29 (.90)
<b>RT in milliseconds</b>				
Pre-switch <sup>a</sup>	9058 (9415)	2932 (1085)	6163 (5011)	3198 (1097)
Post-switch <sup>a</sup>	6965 (3694)	3611 (2280)	6463 (6189)	3586 (1735)
Mixed condition <sup>a</sup>	4735 (2935)	3163 (1723)	4327 (2290)	3224 (1112)
Switch cost in milliseconds	4939 (4464)	1484 (2067)	7129 (16284)	2061 (2071)
<i>SOPT</i>	( <i>n</i> = 8)	( <i>n</i> = 31)	( <i>n</i> = 15)	( <i>n</i> = 34)
Abstract Errors Set Size 6 <sup>a</sup>	1.66 (1.00)	1.01 (.69)	1.44 (.85)	1.14 (.60)
Abstract Errors Set Size 8 <sup>a</sup>	4.70 (1.61)	3.77 (1.85)	5.06 (1.42)	3.94 (1.37)
Abstract Errors Set Size 10 <sup>a</sup>	2.58 (.66)	2.22 (.99)	2.95 (.88)	2.32 (.90)
Object Errors Set Size 6 <sup>a</sup>	1.33 (.83)	.73 (.82)	1.21 (.59)	.66 (.66)
Object Errors Set Size 8 <sup>a</sup>	3.14 (1.87)	2.79 (2.22)	4.76 (1.24)	2.89 (1.98)
Object Errors Set Size 10 <sup>a</sup>	2.42 (.93)	1.65 (1.02)	2.69 (.82)	1.86 (1.03)
<i>PVT</i>	( <i>n</i> = 8)	( <i>n</i> = 31)	( <i>n</i> = 15)	( <i>n</i> = 34)
RT in milliseconds <sup>a</sup>	513 (86)	430 (94)	498 (137)	422 (77)
False starts <sup>b,c</sup>	13.78 (4.96)	9.97 (7.85)	6.29 (4.51)	12.39 (10.30)
<i>Simon Task</i>	( <i>n</i> = 8)	( <i>n</i> = 31)	( <i>n</i> = 15)	( <i>n</i> = 34)
Congruent RT in milliseconds	694 (65)	577 (115)	632 (110)	583 (83)
Incongruent RT in milliseconds <sup>a</sup>	747 (92)	624 (133)	715 (114)	650 (105)
Interference effect	1.15 (.11)	1.07 (.08)	1.13 (.11)	1.11 (.09)

*Note.* M = mean; SD = standard deviation; TD = typically developing; DCCS = Dimensional Change Card Sorting Task; SOPT = Self Ordered Pointing Task; PVT = Psychomotor Vigilance Task.

<sup>a</sup>Main effect of diagnostic group, <sup>b</sup>Interaction effect between diagnostic and language groups, <sup>c</sup>Significant difference between autistic monolinguals and autistic bilinguals.

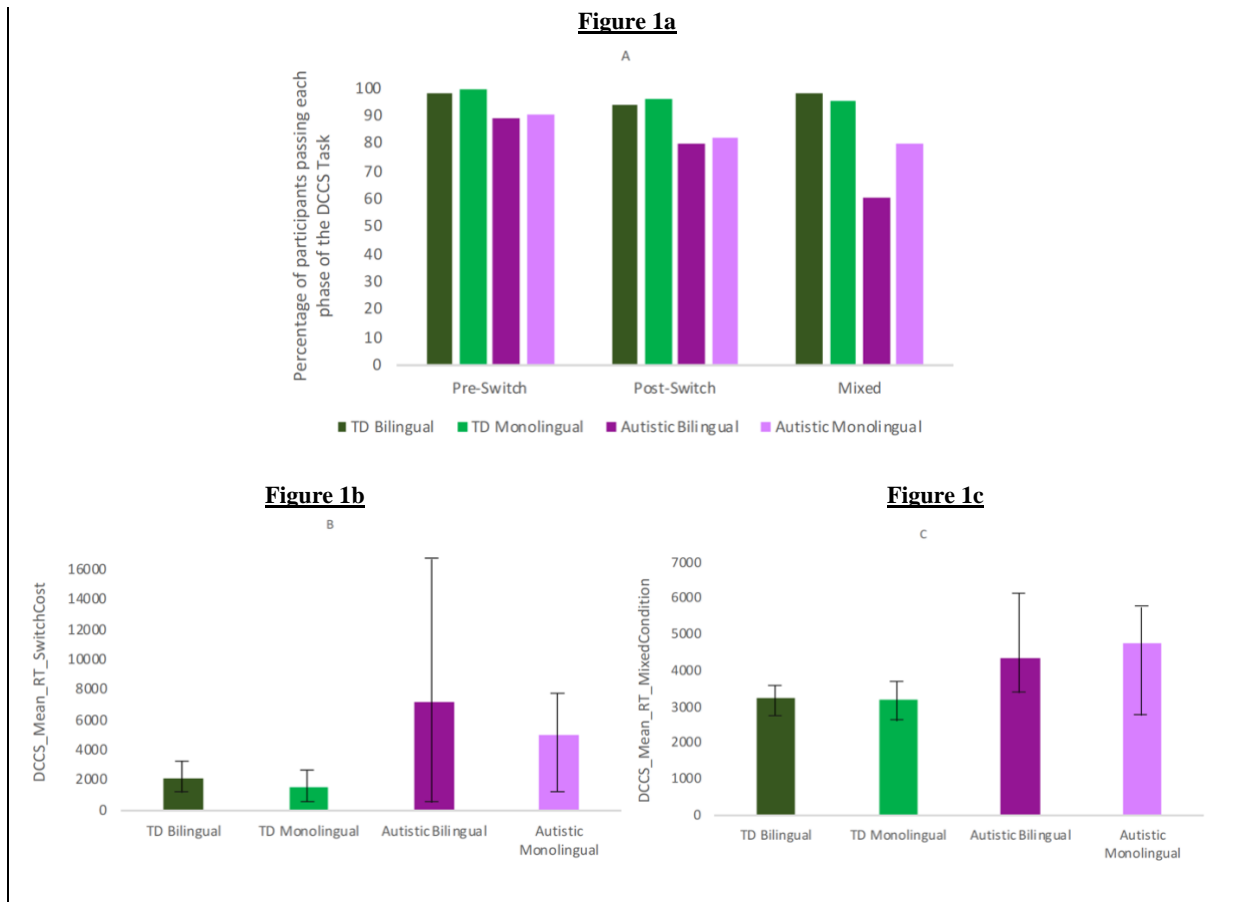
*Flexible Switching. DCCS Accuracy / Passing.* Across all four groups, 86% to 100% of participants passed the pre-switch phase (5 out of 6 correct trials), 75% to 97% of participants passed the post-switch phase (5 out of 6 correct trials), and 60% to 100% of participants passed the mixed condition phase (9 correct trials out of 12) – see Figure 1a. The pre- and post-switch data were not analyzed given the ceiling effects observed (Diamond & Kirkham, 2005).

The alpha level for significance was set at  $p < 0.050$ . For the mixed condition, a Fisher's exact test for analysis of dichotomous outcomes revealed a significant effect of diagnostic group, where the number of autistic participants that passed was significantly lower than the number of TD participants, but only in the bilingual group,  $p = .000$ . The monolingual autistic and monolingual TD groups did not differ significantly,  $p = .121$ . A second Fisher's exact test revealed the main effect of language group was also not significant in both the autistic groups ( $p = .400$ ) and the TD groups ( $p = 1.000$ ).

*DCCS Switch Cost.* The alpha level for significance was set at  $p < 0.025$ . A 2 (diagnostic group) x 2 (language group) ANOVA on switching cost (RT) revealed that the main effect of diagnostic group was not significant,  $F(3, 81) = 4.43, p = .038, \eta_p^2 = .05$  (see Figure 1b). Similarly, neither the main effect of language group,  $F(3, 81) = .20, p = .648, \eta_p^2 = .00$ , nor the interaction between diagnostic group and language group,  $F(3, 81) = 2.81, p = .097, \eta_p^2 = .03$ , were significant.

*DCCS Mean RT Mixed Condition.* The alpha level for significance was set at  $p < 0.025$ . For the mixed condition, only correct trials and trials with  $RT > 200$  ms were considered (Diamond & Kirkham, 2005). For the autistic participants, 15% of trials were excluded and for the TD participants, 13% of trials were excluded. A 2 (diagnostic group) x 2 (language group) ANOVA revealed a significant main effect of diagnostic group,  $F(3, 81) = 7.09, p = .009, \eta_p^2 = .08$  where the TD participants were faster (lower RT scores) than the autistic participants (see Figure 1c). However, the main effect of language group was not significant,  $F(3, 81) = .00, p = .940, \eta_p^2 = .00$ . Finally, the interaction between diagnostic group and language group was not significant,  $F(3, 81) = .44, p = .506, \eta_p^2 = .00$ .

Figure 1: Performance by group: Directly-assessed flexible switching



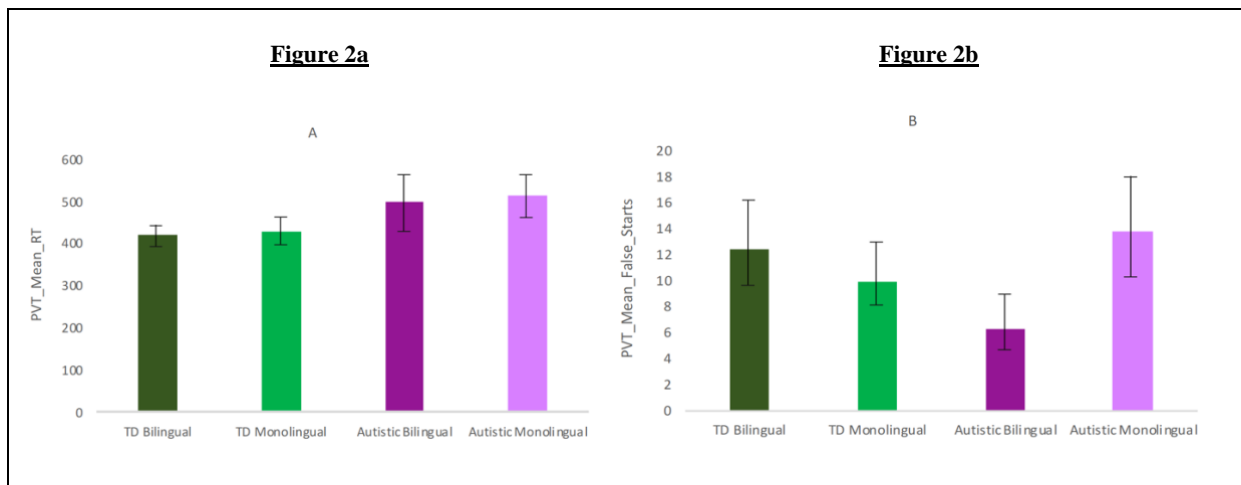
*Note.* Figure 1a displays the percentage of participants passing each phase of the DCCS task; Figure 1b displays the mean RT switch costs and errors bars (95% confidence intervals) for the DCCS task; Figure 1c displays the mean RT on mixed condition trials and errors bars (95% confidence intervals) for the DCCS task.

*Sustained Attention.* Only trials  $\geq$  to 100 ms and  $\leq$  1000 ms were included in the RT analysis. Trials below 100 ms were considered false starts (responses based on anticipation rather than stimulus display) and trials greater than 1000 ms were considered lapses (missed responses) (Lara et al., 2014). For autistic participants, 16% of trials were excluded and for the TD participants, 13% of trials were excluded.

*PVT Mean RTs.* The alpha level for significance was set at  $p < 0.025$ . A 2 (diagnostic group) x 2 (language group) ANOVA revealed a significant main effect of diagnostic group,  $F(3, 84) = 9.97, p = .002, \eta_p^2 = .10$  where TD participants were significantly faster than autistic participants (see Figure 2a). There was no significant main effect of language group,  $F(3, 84) = .41, p = .523, \eta_p^2 = .00$  or interaction between language group and diagnostic group,  $F(3, 84) = .17, p = .677, \eta_p^2 = .00$ .

*PVT false starts.* The alpha level for significance was set at  $p < 0.025$ . A 2 (diagnostic group) x 2 (language group) ANOVA revealed no significant main effect of language group,  $F(3, 84) = 2.57, p = .113, \eta_p^2 = .03$  or a significant main effect of diagnostic group,  $F(3, 84) = .02, p = .88, \eta_p^2 = .00$  (see Figure 2b). There was, however, a significant interaction between language group and diagnostic group,  $F(3, 84) = 6.62, p = .012, \eta_p^2 = .07$ . Post-hoc independent samples t-tests revealed autistic bilinguals had significantly lower mean false starts than autistic monolinguals,  $t(21) = 3.503, p = .002$ .

Figure 2: Performance by group: Directly-assessed sustained attention



*Note.* Figure 2a displays the mean RT and errors bars (95% confidence intervals) for the PVT task; Figure 2b displays the mean false starts and errors bars (95% confidence intervals) for the PVT task.

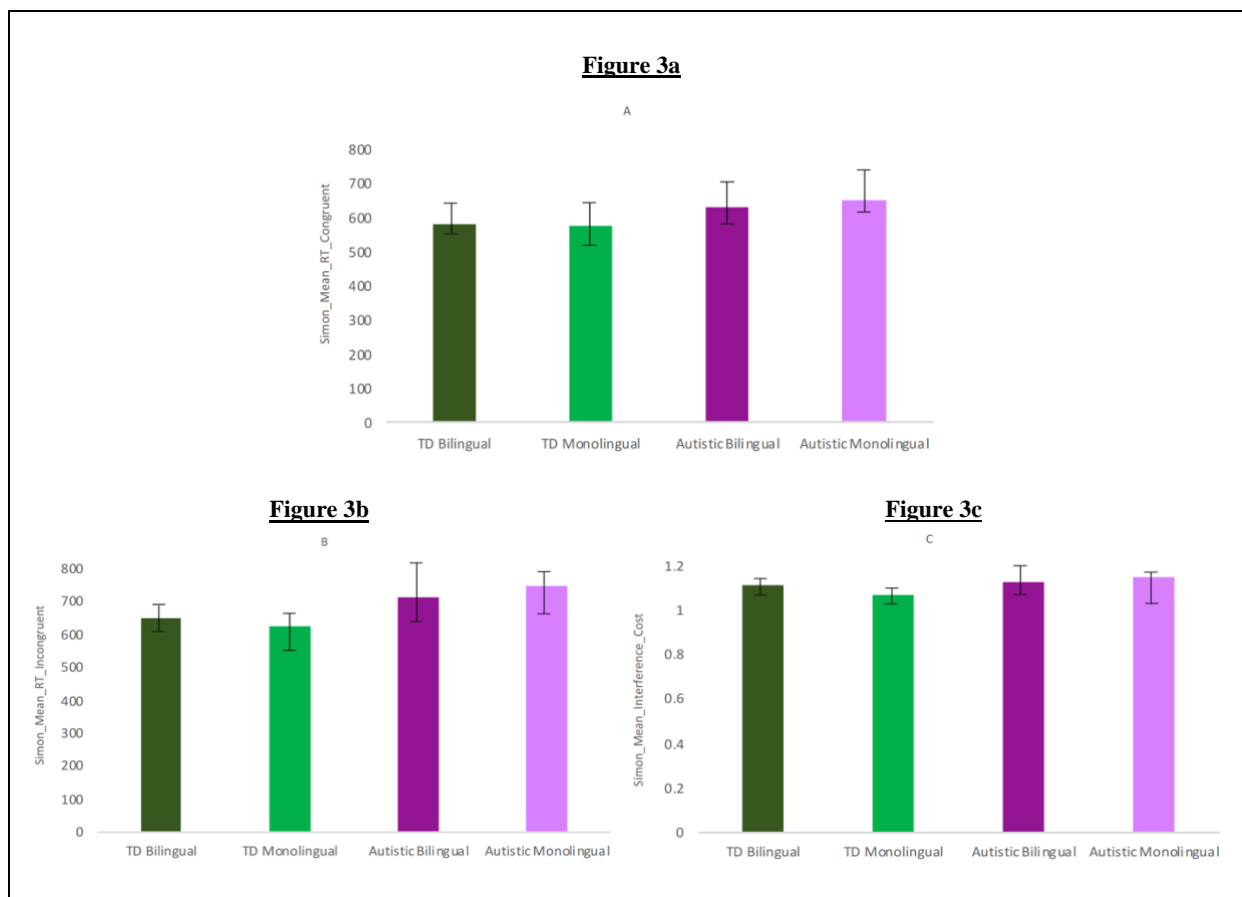
*Interference Control. Congruent RTs.* Only correct trials and RTs  $> 200$  ms and  $< 2000$  ms (di Pellegrino et al., 2007) and were included in the analysis. 16% of the autistic participants' data and 13% of the TD participants' data were excluded. The alpha level for significance was set at  $p < 0.016$ . A 2 (diagnostic group) x 2 (language group) ANOVA demonstrated no significant main effect of diagnostic group,  $F(3, 83) = 5.73, p = .019, \eta_p^2 = .06$  (see Figure 3a). Similarly, there was no significant main effect of language group,  $F(3, 83) = .05, p = .814, \eta_p^2 = .00$ , nor interaction between language group and diagnostic group,  $F(3, 83) = .20, p = .656, \eta_p^2 = .00$ .

*Incongruent RTs.* Only correct trials and trials with RTs  $> 200$  ms and  $< 2000$  ms were included in the RT analysis. For autistic participants, 20% of trials were excluded and for the TD participants, 17% of trials were excluded. The alpha level for significance was set

at  $p < 0.016$ . A 2 (diagnostic group)  $\times$  2 (language group) ANOVA revealed a significant main effect of diagnostic group,  $F(3, 83) = 10.05$ ,  $p = .002$ ,  $\eta_p^2 = .10$ , where the autistic participants were significantly slower on incongruent trials compared to the TD participants (see Figure 3b). However, there was no significant main effect of language group,  $F(3, 83) = .01$ ,  $p = .917$ ,  $\eta_p^2 = .00$ , or an interaction between language group and diagnostic group,  $F(3, 83) = .943$ ,  $p = .334$ ,  $\eta_p^2 = .01$ .

*Interference effect.* The alpha level for significance was set at  $p < 0.016$ . A Mann-Whitney Test revealed no significant main effect of language group,  $U = 782$ ,  $p = .189$ ,  $\eta^2 = .01$  or diagnostic group,  $U = 574$ ,  $p = .169$ ,  $\eta^2 = .02$  (see Figure 3c).

Figure 3: Performance by group: Directly-assessed interference control



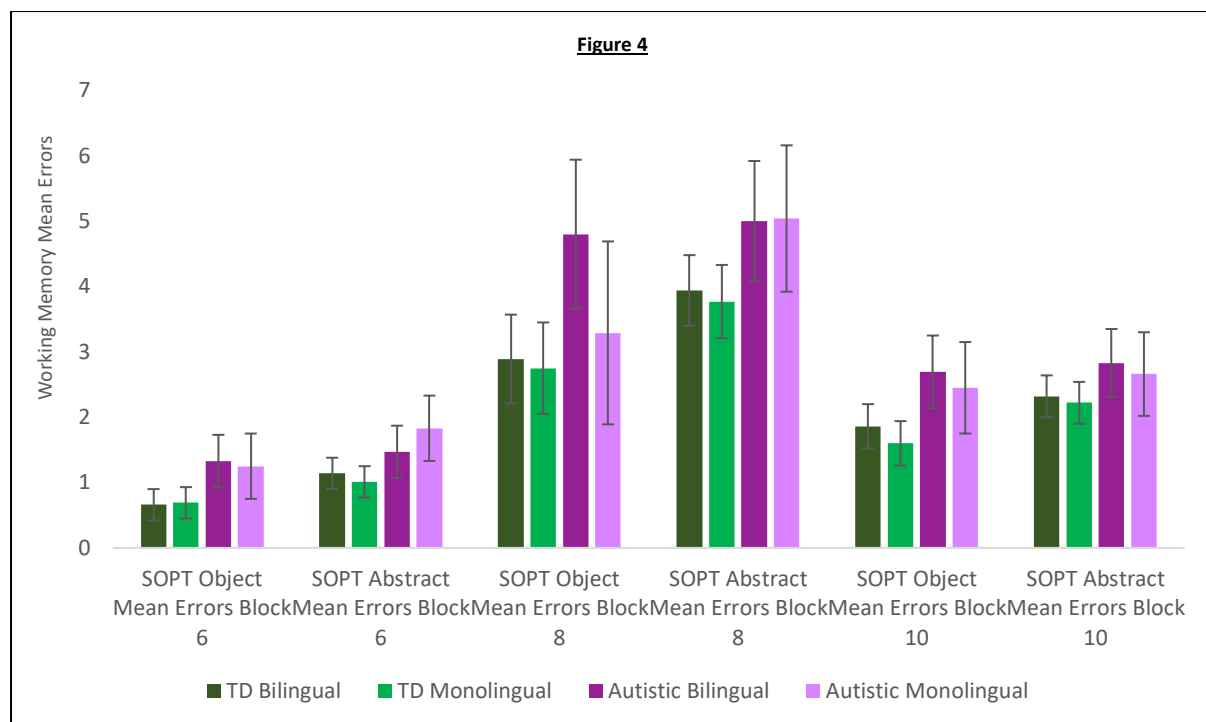
*Note.* Figure 3a displays the mean RT congruent trials and errors bars (95% confidence intervals) for the Simon task; Figure 3b displays the mean RT on incongruent trials and errors bars (95% confidence intervals) for the Simon task, Figure 3c displays the mean interference effect and errors bars (95% confidence intervals) for the Simon task.

*Working Memory: Object and Abstract Versions.* The alpha level for significance was set at  $p < 0.05$ . Separate 2 (diagnostic group) x 2 (language group) ANOVA was run on each condition and revealed a significant main effect of diagnostic group, where the autistic participants made significantly more errors than the TD group on all items (see Figure 4) on: (a) Object version 6-items,  $F(3, 83) = 8.83, p = .004, \eta_p^2 = .09$ ; (b) Object version 8-items,  $F(3, 83) = 4.58, p = .035, \eta_p^2 = .05$ ; (c) Object version 10-items,  $F(3, 83) = 9.40, p = .003, \eta_p^2 = .10$ ; (d) Abstract version 6-items,  $F(3, 84) = 6.87, p = .010, \eta_p^2 = .07$ ; (e) Abstract version 8-items,  $F(3, 84) = 6.61, p = .012, \eta_p^2 = .07$ ; (f) Abstract version 10-items,  $F(3, 84) = 4.57, p = .035, \eta_p^2 = .05$ .

There was no significant main effect of language group on any condition (see Figure 4): (a) Object version 6-items,  $F(3, 83) = .25, p = .618, \eta_p^2 = .00$ ; (b) Object version 8-items,  $F(3, 83) = 2.74, p = .101, \eta_p^2 = .03$ ; (c) Object version 10-items,  $F(3, 83) = .80, p = .372, \eta_p^2 = .01$ ; (d) Abstract version 6-items,  $F(3, 84) = .05, p = .814, \eta_p^2 = .00$ ; (e) Abstract version 8-items,  $F(3, 84) = .43, p = .514, \eta_p^2 = .00$ ; (f) Abstract version 10-items,  $F(3, 84) = 1.03, p = .313, \eta_p^2 = .01$ .

Similarly, there was no significant interaction between language group and diagnostic group on any condition (see Figure 4): (a) Object version 6-items,  $F(3, 83) = .01, p = .905, \eta_p^2 = .00$ ; (b) Object version 8-items,  $F(3, 83) = 2.14, p = .147, \eta_p^2 = .02$ ; (c) Object version 10-items,  $F(3, 83) = .01, p = .916, \eta_p^2 = .00$ ; (d) Abstract version 6-items,  $F(3, 84) = 0.97, p = .327, \eta_p^2 = .01$ ; (e) Abstract version 8-items,  $F(3, 84) = .05, p = .812, \eta_p^2 = .00$ ; (f) Abstract version 10-items,  $F(3, 84) = .35, p = .555, \eta_p^2 = .00$ .

Figure 4: Performance by group: Directly-assessed working memory



*Note.* Figure 4 displays the mean errors and errors bars (95% confidence intervals) for the SOPT task in both object and abstract versions.

## Discussion

The current study investigated the impact of bilingualism in autistic and TD children, on a specific set of EF skills, namely interference control, flexible switching, sustained attention and working memory. All data were collected in the United Arab Emirates. To our knowledge, this is the first investigation to (a) include Arabic-speaking children and (b) take place in the Arab world / Arab states. Working in this setting provides a valuable opportunity to diversify autism research samples, given that the vast majority of psychological research has been drawn from WEIRD (western, educated, industrial, rich, and democratic) samples (Henrich, Heine, & Norenzayan, 2010; Nielsen, Haun, Kärtner, & Legare, 2017).

The adaptive control hypothesis predicts that the EF domains of interference control, sustained attention and flexible switching - should be subject to a positive impact of bilingualism, for this sample from a dual-language context. We also included an assessment of working memory, which is not hypothesized to be influenced by bilingualism, as an active EF control task. We found no support for this prediction by the adaptive control hypothesis. Across a range of reaction time and accuracy variables, no main effects of language group were detected. Specifically, in the typically-developing sample, bilingualism had no



discernable effect on EF, in line with some other reports (Gonzalez-Barrero & Nadig, 2017; Paap & Greenberg, 2013).

Another prediction by the adaptive control hypothesis is that some aspects of bilingual language use (e.g., switching tendencies, current language exposure) should correlate with some aspects of EF performance in the bilingual groups (both autistic and typically developing), regardless of any comparisons with monolinguals. While these potential relationships were not explored as part of this work, future research should endeavor to test this prediction.

Our findings also do not lend support to another prominent theoretical model of bilingual language use and EF, such as the brain training hypothesis. While the current work was not designed to test the full range of predictions of the brain training hypothesis, we note there were no main effects of language group across relevant EF domains.

We did, however, find consistent effects of diagnostic group, such that autistic children made more errors and were slower to respond in nearly every outcome variable assessed. The presence of this pattern indicates that despite the modest sample size, we did have adequate power to detect effects of interest in all tasks. Our data yielded one instance of an interaction between language group and diagnostic status. In sustained attention, our autistic bilingual participants out-performed their monolingual peers, and even typically developing peers (both bilingual and monolingual) by making significantly fewer false starts. This finding might suggest less impulsivity or perhaps greater patience with the task within the autistic bilingual group.

There are some limitations that must be addressed. First, while we made every effort to maximize our sample size via nation-wide collaborations (participants were recruited from 20+ institutions located across three cities), we acknowledge that our monolingual autistic sample is small compared to the other groups. As this can result in a loss of power, we followed Maxwell and Delaney's (2003) recommendation to use Type III sums of squares which is robust to variable sizes of groups being compared. Second, although selected with autistic participants in mind (e.g., computerized, explicit), the EF measures used in the current work lack validity and reliability information for use with autistic samples. Third, we were reliant on a single EF measure per domain, in an effort to reduce assessment demands on participants. Future research would benefit from the inclusion of multiple direct measures to assess each EF domain. For example, the sustained attention task revealed a bilingual advantage for autistic children, and had a large number of trials. It is possible that the

relatively small number of trials on the flexible switching mixed condition might have masked potential effects of bilingualism.

Finally, it must be acknowledged that the UAE as a nation is a multilingual environment. All of the children in this study, including monolinguals, are exposed to a second language in their community. However, this concern is ameliorated by some key factors. Our monolingual children were below threshold on our robust proficiency criteria, drawn from monolingual homes and taught / instructed in the same language as their home language at school, meaning that the impact of the wider cultural context was significantly diluted. Ultimately, our results should be interpreted as relevant to bilingual language use and proficiency, rather than mere passive exposure.

Although novel, the finding of a bilingual advantage for autistic children in this sustained attention outcome variable should be taken as preliminary evidence and interpreted with caution, given the lack of a bilingual advantage for autistic children in other outcome variables of sustained attention (i.e., reaction times). In addition, we detected no bilingual advantage for TD children across all outcome variables from the sustained attention task. A replication with a larger but similarly well-characterized sample and ideally with multiple measures of sustained attention would be a useful next step. In flexible switching, the TD bilinguals showed greater accuracy than autistic bilinguals, but there were no differences between the monolingual groups in this case. Visualization of the data suggests this result was driven by very poor performance of the autistic bilingual group on this task. Our finding of no TD bilingual advantage on any EF outcome variable was echoed by other studies investigating bilingualism in childhood autism, using similar measures and bilingualism categorization (Gonzalez-Barrero & Nadig, 2017).

We did not find evidence of widespread executive function advantages associated with being bilingual in our sample. Since autistic children generally struggle with executive function tasks like those in our study, there is substantial room for improvement in executive domains. This might make it easier to detect bilingual advantages in an autistic than a TD sample, and so it is striking that we did not on the whole find bilingual advantages. On the other hand, our data also make it clear that bilingualism does not result in a disadvantage for autistic children. Despite concerns from parents and practitioners, we found no evidence that autistic children's executive function abilities are detrimentally affected by learning and using two languages.

The investigation of bilingualism in matched autistic and TD groups, recruited in a dual-language switching environment has a number of strengths. We captured a range of EF

components relevant to the adaptive control hypothesis, and used a rigorous procedure to determine bilingual and monolingual status. Our sample, while modest, was well matched on age, multiple components of socio-economic status, and non-verbal IQ. It is unsurprising that across diagnostic, language, and interaction analyses, the size of the effects ranged from low to medium, consistent with previous literature published at this interface. Nonetheless, our autistic participants were cognitively able, school-aged, proficient bilinguals, living in dual-language contexts and so replications and extensions are required to determine the generalizability of our results.

In summary, our current study showed that performance on most tests assessing EF abilities did not differ among monolingual and bilingual children, which speaks against the adaptive control hypothesis. In our sample, the regular use of two languages did not positively influence executive functions in either autistic or TD children, except one measure of sustained attention where bilingual autistic children showed an advantage compared to their monolingual peers. However, this single finding should be interpreted with caution. On all other tests, autistic children made more errors and were slower to respond, regardless of their language group. Together, these findings join a growing body of literature showing that bilingualism does not negatively impact the executive functions of autistic children.

### **Declaration of Conflict of Interests**

Authors declare that there is no conflict of interest.

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## **Thesis-integrated discussion**

In terms of thesis aims, I have explored the impact of bilingualism on the EF skills of autistic children, using carefully selected directly-assessed measures of EF that capture EF abilities at one point in time. Children were located in a dual-language switching environment, thus allowing me to test the predictions of the ACH model. I have shown that bilingualism does not negatively impact the executive functions of autistic children, and in fact, might confer an advantage for autistic children in sustained attention (one outcome variable; mean false starts using the PVT Task). However, I did not find evidence of widespread executive function advantages associated with being bilingual in my sample; therefore, I did not find support for the ACH model. The next step is to examine this same issue using informant-report measures that capture EF over a wider time span and everyday types of situations. The next Chapter, Chapter 4, will report on these findings.

## Chapter 4: The impact of bilingualism on everyday executive functions of English-Arabic autistic children: Through a parent-teacher lens

This chapter has been submitted for publication to the academic journal ‘Journal of Autism and Developmental Disorders’ with the following citation: **Sharaan, S.**, MacPherson, S.E., Fletcher-Watson, S. (2021). The Impact of Bilingualism on Everyday Executive Functions of English-Arabic Autistic Children: Through a Parent-Teacher Lens. Below is the full text of the submitted manuscript.

**Abstract:** There is evidence that autistic children may have reduced executive function skills, contributing to day-to-day difficulties. Much remains unknown regarding the influence of bilingualism on the executive functions of autistic children. We investigated the influence of bilingualism on sustained attention, interference control, flexible switching and working memory, in Arabic-English autistic children ( $n = 27$ ) and their typically developing peers ( $n = 53$ ), aged 5 to 12 years old. Parents and teachers completed rating measures assessing children’s daily EF abilities. Results showed generalized positive effects for bilingual autistic children relative to their monolingual peers across all EF domains, but using parent ratings only. Teacher ratings revealed equivalent performance between bilingual and monolingual children for autistic and typically-developing groups. The findings indicate that bilingualism does not negatively impact the executive function skills of autistic children, and that it might mitigate difficulties faced on a day-to-day basis across a number of EF domains.

**Keywords:** Dual Language, Second Language Exposure, Autism, Cognition

### Introduction

The role of executive functions has been well-established across a range of educational (Allan, Hume, Allan, Farrington, & Lonigan, 2014; Dekker, Ziermans, Spruijt, & Swaab, 2017) and social domains (Hughes, White, Sharpen, & Dunn, 2000; Murphy, Shepard, Eisenberg, & Fabes, 2004), as well as having an influence on quality of life (Tangney, Baumeister, & Boone, 2004). Executive dysfunction in autism has been widely evidenced

(Demetriou et al., 2017; Lai et al., 2017), though large individual differences in performance have also been demonstrated (Geurts, Sinzig, Booth, & Happ, 2014). Furthermore, deficits in executive function have been associated with low quality of life in autistic people (Vries & Geurts, 2015). While heterogeneity in autism has been clearly evidenced in the EF domain, our understanding of the elements that moderate the development of EF and outcomes in autism remains poor (Demetriou et al., 2017). One moderating element could be exposure to two languages.

Bilingualism is an ability common to the majority of the world's population (Grosjean, 2010). A spectrum of bilingualism markers have been associated with improved EF development, including language acquisition at an earlier age (Kapa & Colombo, 2013), higher proficiency in languages (Niharika & Ramesh Kumar, 2013), and regularly switching between languages (Prior & Gollan, 2011). The influence of bilingualism on EFs is a heavily debated topic, with findings in favor of (Barac, Bialystok, Castro, & Sanchez, 2014; Bialystok, 2001) and against (Dick et al., 2019; Paap & Greenberg, 2013) a bilingual advantage. For in-depth accounts of the complexities surrounding the literature on bilingualism and EF, see Paap and Greenberg (2013) and de Bruin, Treccani, and Della Sala (2015). While there are null results, disadvantages in EF performance are seldom, if ever, evidenced for bilinguals (Dick et al., 2019; Gonzalez-Barrero & Nadig, 2017).

One of the notable frameworks that propose an explanation for the relationship between bilingualism and EF is the Adaptive Control Hypothesis (ACH) (Green & Abutalebi, 2013). This framework argues that the relationship between bilingualism and EF is fundamentally determined by language context. In a 'single language context', the two languages are used in separate and distinct contexts (e.g., using English at work and Japanese at home), resulting in no switching between the two languages. In a 'dual language context', both language are used in the same context, resulting in regular switching between the two languages. Finally, in a 'dense language context', there is alternation between the two languages within single sentences, and/or adaptation of words from one language to fit another. The adaptive control hypothesis suggests that EF skills such as flexible switching, inhibitory control, and sustained attention would be most enhanced by a dual language context. This theoretical difference between language contexts may be one reason why evidence to date on the effect of bilingualism on EF is so equivocal.

The adaptive control hypothesis has received empirical support, particularly from studies investigating the EF domains of flexible switching and interference control in typically developing children. For instance, a study with early bilinguals highlighted that the

frequency with which they switch between languages on a day-to-day basis significantly predicted error rates on an experimental flexible switching task (number-letter task) (Soveri, Rodriguez-Fornells, & Laine, 2011). Another study using a color-shape flexible switching task demonstrated an advantage for early bilinguals who reported regular language switching, and equivalent performance between monolinguals and early bilinguals who reported less regular language switching (Prior & Gollan, 2011). Similarly, there is support for a link between interference control abilities (e.g., using a Flanker task) and frequency of language switching in early bilinguals (Verreyt, Woumans, Vandelandotte, Szmalec, & Duyck, 2016). Together, these findings provide supporting evidence for the theoretical relationship between language switching and the prime abovementioned EF skills in bilinguals.

A limited but growing evidence-base shows that bilingualism does not result in disadvantages for autistic children in language domains (see Uljarević, Katsos, Hudry, & Gibson, 2016 for a review). In the domain of EF, the evidence is even more limited, but one study reported equivalent performance between autistic children who received second language exposure and those who did not, using parent ratings that assess problem solving, attentional control, behavioral control and emotional control (Iarocci, Hutchison, & O'Toole, 2017). Similarly, equivalent performance between bilingual and monolingual autistic children was demonstrated for directly-assessed measures of inhibitory control and flexible switching (Li, Oi, Gondo, & Matsui, 2017). In the study by Iarocci et al. (2017), the authors note that despite a lack of statistically significant differences in EF performance between single and dual-language exposure autistic children, those with a second language exposure were less likely to produce EF difficulties that are clinically concerning. These results were echoed in a more recent investigation by Ratto, Potvin, Pallathra, Saldana, and Kenworthy (2020), on inhibitory self-control and flexible switching.

Three studies provided preliminary support for the hypothesis that bilingual autistic children have an advantage compared to monolingual autistic children in inhibitory control (Li et al., 2017), flexible switching (Gonzalez-Barrero & Nadig, 2017), and sustained attention (Sharaan, Fletcher-Watson, & MacPherson, 2020). In each study, however, only one outcome variable (out of two or more outcome variables) revealed an advantage for autistic bilinguals, so it is not clear whether these findings are robust. Furthermore, in the second study (Gonzalez-Barrero & Nadig, 2017), no bilingual advantage was reported for autistic participants on a parent report measure assessing flexible switching. Taken together, these quantitative findings strongly support the idea that bilingualism is not harmful to autistic children's language and EF development, and may result in some advantages.

The current investigation focuses on the influence of bilingualism on a set of EF skills that have been identified as vulnerable in autism and are relevant to the adaptive control hypothesis – sustained attention, flexible switching, and interference control. In addition, working memory is included as an active control EF but as it is not driven by the ACH model of interest, it is not hypothesized to be directly impacted by bilingualism. We selected informant-report measures to capture “trait-like” everyday capacities, which are relatively stable over time (Samyn, Roeyers, Bijttebier, Rosseel, & Wiersema, 2015), seeking input from both teachers and parents to increase robustness of our findings. This investigation took place in a dual-language environment (the type of language context most likely to advantage our shortlisted EFs according to the ACH); the United Arab Emirates (UAE), where the presiding language of Arabic is in the top five most spoken languages of the world, with more than 240 million native speakers (Adams & Fleck, 2015).

In reference to the theoretical model under investigation (i.e., Adaptive Control Hypothesis), we hypothesize that bilingual children will outperform monolingual children on measures of flexible switching, sustained attention and interference control, on both parent and teacher ratings of EF. We hypothesize there will be no effects of bilingualism on working memory. In addition, we will explore interactions between diagnostic status and bilingualism in their effect on informant EF scores, but hold no firm hypothesis about EF performance between autistic and TD bilinguals. In relation to agreement between different informants, we will investigate whether parent and teacher ratings a) correlate with one another, and b) show differential patterns when comparing diagnostic (autism / TD) and language (bilingual / monolingual) groups.

## **Methods**

### *Participants*

One hundred and fifteen children aged between 5 and 12 years were recruited into the study ( $M = 111.37$  months,  $SD = 21.43$  months), but only 80 children had a consistency index standard score  $> 75$  on the EF rating scale (see below), therefore, after excluding 35 participants whose raters showed an inconsistent response style, 80 participants with ratings showing a consistent response style were carried forward for analyses.

Monolingual children spoke either English ( $n = 47$ ) or Arabic ( $n = 3$ ), and bilingual children spoke both English and Arabic. All bilingual children spent considerable periods of time in dual-language switching contexts, where Arabic and English are utilized within the



same context (i.e., school and / or home environments). The primary inclusion criteria for autistic children was a formal diagnosis of autism based on DSM-IV or DSM-V criteria, established by the children's educational institution (e.g., schools) or primary caregiver. Children with a range of non-verbal IQ scores on the Raven's Colored Progressive Matrices (CPM; Raven et al., 1990) were recruited to increase inclusive participation into the study. Children had no uncorrected visual or hearing deficits, or co-morbidities (e.g., ADHD).

The Child Language Experience and Proficiency Questionnaire (Marian, Blumenfeld, & Kaushanskaya, 2007) (collecting language history, current exposure, current use and proficiency data) was administered to parents, in either Arabic or English. Expressive vocabulary was measured with the Picture Naming Test (PNT) (Kharkhurin, 2008) in Arabic and/or English. Receptive vocabulary was measured with the Peabody Picture Vocabulary Test, 4<sup>th</sup> ed. (PPVT-4) in English (Dunn & Dunn, 2007) and the Arabic Picture Vocabulary Test (APVT) (Shalan, 2010) in Arabic.

Children's bilingual status was determined based on an amalgam of the following indices: (1) > 20% of current exposure to each of the two languages at home or school, according to parent report, (2) > 20% of current active speaking in each of the two languages at home or school, according to parent report, (3) > 20% proficiency score in each of the two languages as per a direct expressive vocabulary measure, scored by the researcher.

Children's monolingual status was determined based on a combination of the following indices: (1) had not been exposed to a language other than Arabic (or English if their first language was English) for more than 20% of their lifetime, (2) if exposed to a second language, < 20% of current active speaking at home or school, according to parent report, (3) if exposed to a second language, < 20% proficiency score (24 correct item-responses out of 120 items) as per a direct expressive vocabulary measure, scored by the researcher. Proficiency was determined based on the accuracy of children's verbal responses to 120 items in the PNT. Categories of language proficiency included high proficiency in both languages (66% - 100%), medium proficiency (40% - 65%), and low proficiency (21% - 39%) (Marian et al., 2007).

Ethical approvals were obtained from the University of Edinburgh (School of Philosophy, Psychology and Language Sciences, Application 102-1718/2), the Abu Dhabi Department of Education and Knowledge, and the UAE Ministry of Community Development. All parents and participants gave informed consent.

Details of participant characteristics are presented in Table 6. A series of one-way analysis of variance (ANOVA) confirmed significant differences between the 4 groups (autistic bilingual, autistic monolingual, TD bilingual, TD monolingual) on non-verbal IQ ( $p = .000$ ). There were no significant differences between the groups on chronological age ( $p = .475$ ), maternal continuous years of education ( $p = .568$ ) or maternal minimum education level ( $p = .247$ ).

**Table 6.** Participant Demographics by Group: Informant-report EF

	Monolingual		Bilingual	
	Autistic (N = 21) M (SD)	TD (N = 29) M (SD)	Autistic (N = 6) M (SD)	TD (N = 24) M (SD)
Participant age ( <i>months</i> )	104.76 (23.90)	114.48 (25.98)	116.17 (16.31)	110.08 (19.54)
CPM (grade)	6.76 (2.84)	2.52 (1.52)	3.50 (1.76)	2.42 (1.31)
Maternal education level	5.24 (1.64)	5.90 (1.29)	5.00 (1.89)	5.67 (0.86)
Maternal education ( <i>years</i> )	16.10 (1.99)	16.62 (1.54)	16.83 (3.92)	16.83 (1.20)
Gender (M/F)	17/4	6/23	4/2	11/13

*Note.* M = mean; SD = standard deviation; TD = typically developing; CPM = Colored Progressive Matrices nonverbal IQ grade (Grade 1 = intellectually superior (score lies at or above the 95<sup>th</sup> percentile for individuals of that age group); Grades 2 and 3 = definitely above average (score lies at or above the 75<sup>th</sup> percentile for individuals of that age group); Grades 4 and 5 = intellectually average (score lies between the 25<sup>th</sup> and 75<sup>th</sup> percentile for individuals of that age group); Grades 6 and 7 = intellectually below average (score lies at or below the 25<sup>th</sup> percentile for individuals of that age group); Grade 8 = intellectually impaired (score lies at or below the 5<sup>th</sup> percentile for individuals of that age group).

*Language Context.* English is generally considered to be the lingua franca as approximately 90% of the UAE's population is made up of non-citizens (De Bel-Air, 2015; United Nations, 2016). In addition to the presence of an English-Arabic dual language environment, three versions of spoken Arabic are present, representing a triglossic context. These include: Classical Arabic (i.e., a version of Arabic adopted by the Quran and literary

projects), Modern Standard Arabic (i.e., a version of Arabic used in formal communications, for example, schooling and the news media), and Colloquial Arabic (i.e., Arabic associated with dialects used in everyday-type contexts) (Sabbah, 2015). In a study focused on language education in the UAE, Al Sharhan (2007) stated that development of all three varieties of Arabic was a core aspect of Emirati children's language education.

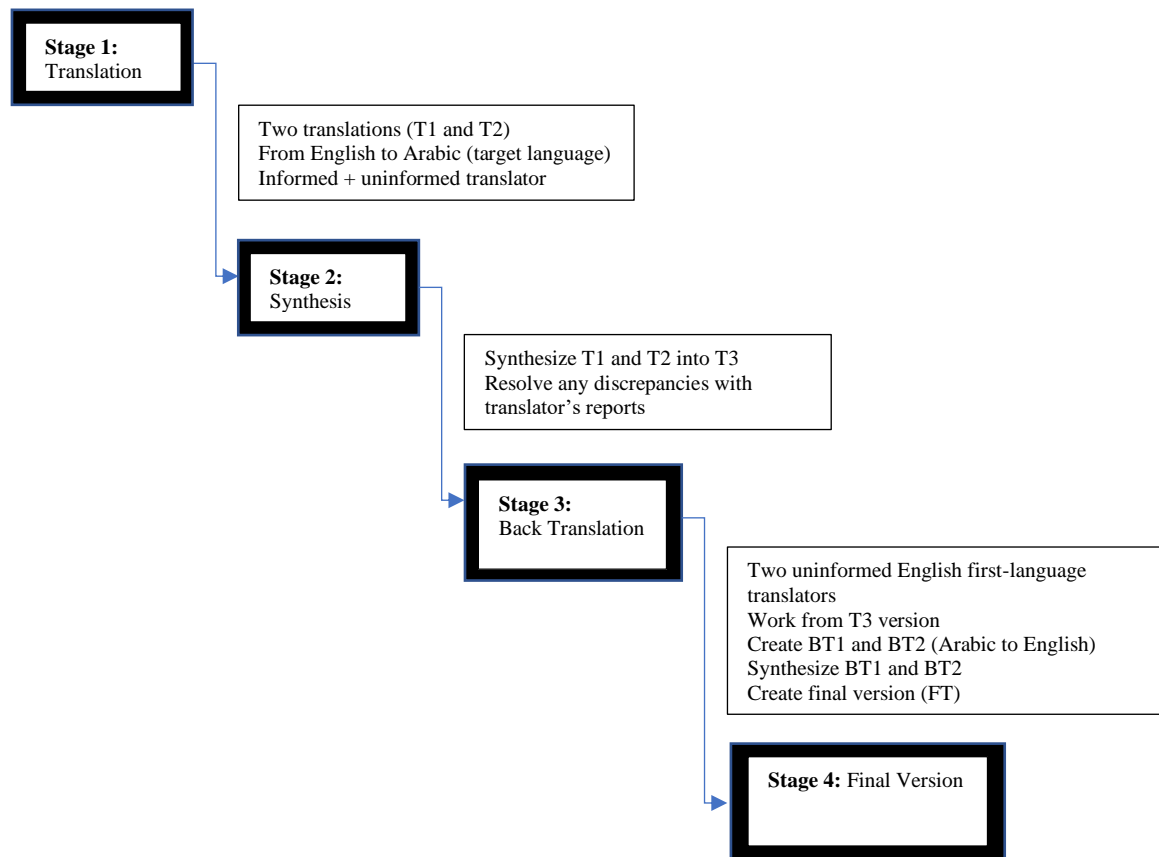
*Materials.* The Comprehensive Executive Function Inventory (CEFI; Goldstein & Naglieri, 2014) is an EF rating scale comprised of 100 items for individuals aged 5-18 years, with both parent and teacher rating forms. The four sub-scales of the CEFI are: interference control, flexible switching, sustained attention, and working memory. Parents and teachers are asked to rate behaviors observed during the last four weeks. Standard scores < 90 indicate a weakness in executive function. The CEFI is highly correlated with similar and more widely used measures like the BRIEF (Gioia, Isquith, Guy, & Kenworthy, 2000) but it is more precisely normed than the BRIEF (Goldstein & Naglieri, 2014) and also captures the 'sustained attention' EF domain, unlike the BRIEF. The test has reported very good to excellent internal reliability and test-retest stability (Goldstein & Naglieri, 2014). The CEFI is only available in English, and thus, an Arabic version was created with publisher approval – the procedure is detailed below.

For the initial translation, two independent forward translations were made from English to Arabic by bilingual translators whose mother tongue is Arabic. One of the translators did not have knowledge of the CEFI items being quantified (as per publisher requirements) nor a developmental or clinical background. A written report was produced based on each translation (T1 and T2) with comments regarding challenges and reasoning for their choices recorded. Both translations were then combined into one common translation (T3). Any challenges resulting from synthesizing the translations and ways in which they were resolved were addressed in a separate written report.

The next stage involved two translators (with English as their mother tongue) who are blind to the English version back-translating the CEFI from Arabic to English to check validity (i.e., Arabic and English versions reflect the same item content). They too did not have knowledge of the concepts being quantified nor a developmental or clinical background to avoid biases. The outcomes of this collaboration were two backtranslations (BT1 and BT2). Both translations were then synthesized into the final version (FT). Decisions pertaining to achieving equivalence between the English and Arabic versions in semantic equivalence, idiomatic equivalence, experiential equivalence, and conceptual equivalence

(Beaton, Bombardier, Guillemin, & Ferraz, 2000) were achieved via this translation methodology (see Figure 19).

Figure 2.3: CEFI Translation Methodology (from English to Arabic)



Adapted from (Beaton et al., 2000)

All scoring was computerized via the CEFI Scoring Software Program and the MHS Online Assessment Center (<https://www.mhsassessments.com>) which provides an automated procedure for addressing missing item scores. In addition to EF sub-scales, the CEFI provides standard scores for quality indicators: (a) consistency index (i.e., how consistent / inconsistent the rater's responses were), (b) positive impression scale (i.e., the extent to which a rater creates an approving impression of the child), (c) negative impression scale (i.e., the extent to which a rater creates an unapproving impression of the child).

*Procedure.* Participant recruitment was facilitated via the support of 22 organizations (e.g., autism centers, mainstream schools with inclusion programs for autistic children), across three Emirates (Abu Dhabi, Dubai, Sharjah) from March 2018 to April 2019. Recruitment calls were dispatched through participating schools and centers as well as

through research mailing lists, social media groups, and autism-related conferences and workshops. Participants were seen one by one during a research session where language screening assessments were administered. Language status (bilingual or monolingual) was determined following the completion of the research session, upon scoring ratings from direct and parent language measures. CEFI Parent and Teacher forms were administered and collected from families (filled out by either mothers or fathers) and teachers (either head teachers or assigned therapists or shadow teachers at mainstream schools and centers) during home, school or center visits. Raters were administered forms in their language preference (English or Arabic).

*Analysis Methods.* Statistical analyses were performed in SPSS Version 24. The data were all found to be normally distributed. Across continuous outcome variables, two-way analysis of variance (ANOVA) were conducted with diagnostic group (Autistic, TD) and language group (monolingual, bilingual) as between subject factors. No co-variate adjustments nor further quality indicators (i.e., positive impression and negative impression scale thresholds) were included in this analyses due to power considerations. Higher standard scores on the CEFI indicate better EF abilities.

## Results

Tables 2 and 3 show the mean standard scores and standard deviations as per parent and teacher EF ratings for children with a consistency index standard score > 75.

**Table 7.** Means and standard deviations from parent-report EF measure by group

	Monolingual		Bilingual	
	Autistic M (SD)	TD M (SD)	Autistic M (SD)	TD M (SD)
PR: Flexible Switching <sup>B,C</sup>	(n = 21 ) 87.29 (16.04)	(n = 29 ) 109.00 (13.51)	(n = 6) 106.83 (17.08)	(n = 24 ) 104.25 (13.90)
PR: Interference Control <sup>A,B,C</sup>	(n = 21 ) 79.33 (14.60)	(n = 29 ) 106.59 (10.57)	(n = 6) 105.83 (10.81)	(n = 24 ) 102.67 (11.54)

PR: Sustained Attention <sup>A,B,C</sup>	(n = 21 )	(n = 29 )	(n = 6)	(n = 24 )
	86.43 (13.78)	105.48 (12.83)	101.67 (16.81)	104.96 (11.69)
PR: Working Memory <sup>B,C</sup>	(n = 21 )	(n = 29 )	(n = 6)	(n = 24 )
	85.57 (19.21)	107.10 (13.86)	104.33 (14.73)	102.57 (14.61)

*Note.* M = mean; SD = standard deviation; TD = typically developing; PR = parent rating (green shaded rows); <sup>A</sup> = diagnostic effect; <sup>B</sup> = language effect; <sup>C</sup> = interaction effect.

**Table 8.** Means and standard deviations from teacher-report EF measure by group

	Monolingual		Bilingual	
	Autistic M (SD)	TD M (SD)	Autistic M (SD)	TD M (SD)
TR: Flexible Switching <sup>A</sup>	(n = 13 ) 81.23 (12.43)	(n = 8 ) 113.75 (13.83)	(n = 9) 85.00 (5.91)	(n = 7 ) 108.71 (16.28)
TR: Interference Control <sup>A</sup>	(n = 13 ) 80.23 (16.05)	(n = 8 ) 111.00 (15.87)	(n = 9) 82.22 (10.12)	(n = 7 ) 106.29 (15.35)
TR: Sustained Attention <sup>A</sup>	(n = 13 ) 83.46 (14.14)	(n = 8 ) 112.63 (15.57)	(n = 9) 88.00 (9.05)	(n = 7 ) 105.29 (13.85)
TR: Working Memory <sup>A</sup>	(n = 13 ) 82.54 (12.24)	(n = 8 ) 107.88 (14.50)	(n = 9) 83.44 (4.41)	(n = 7 ) 105.86 (12.14)

*Note.* M = mean; SD = standard deviation; TD = typically developing; TR = teacher rating; <sup>A</sup> = diagnostic effect

**Group Differences on EF Outcomes.** *Flexible Switching (Parent).* A 2 (diagnostic group) x 2 (language group) ANOVA on parent-rated flexible switching revealed that the main effect of diagnostic group was significant,  $F(1, 76) = 5.92, p = .017, \eta_p^2 = .07$  where TD participants displayed significantly better flexible switching than the autistic participants. The main effect of language group was not significant,  $F(1, 76) = 3.54, p = .064, \eta_p^2 = .04$ , however, the interaction between diagnostic group and language group was significant,  $F(1,$

76) = 9.55,  $p = .003$ ,  $\eta_p^2 = .11$ . Post-hoc independent samples t-tests revealed autistic bilinguals had significantly better flexible switching than autistic monolinguals,  $t(25) = -2.59$ ,  $p = .015$ .

*Flexible Switching (Teacher)*. A 2 (diagnostic group) x 2 (language group) ANOVA on teacher-rated flexible switching revealed a significant main effect of diagnostic group,  $F(1, 33) = 26.45$ ,  $p = .000$ ,  $\eta_p^2 = .44$  where the TD participants displayed significantly better flexible switching than the autistic participants. However, neither the main effect of language group,  $F(1, 33) = .09$ ,  $p = .758$ ,  $\eta_p^2 = .00$ , nor the interaction effect between diagnostic group and language group,  $F(1, 33) = 1.73$ ,  $p = .198$ ,  $\eta_p^2 = .05$ , were significant.

*Sustained Attention (Parent)*. A 2 (diagnostic group) x 2 (language group) ANOVA on parent-rated sustained attention revealed a significant main effect of diagnostic group,  $F(1, 76) = 10.07$ ,  $p = .002$ ,  $\eta_p^2 = .11$  where TD participants displayed significantly better sustained attention than the autistic participants. There was a significant main effect of language group,  $F(1, 76) = 4.36$ ,  $p = .04$ ,  $\eta_p^2 = .05$  where bilinguals exhibited significantly better sustained attention than monolinguals. The interaction effect between language group and diagnostic group was also significant,  $F(1, 76) = 5.01$ ,  $p = .02$ ,  $\eta_p^2 = .06$ . Post-hoc independent samples t-tests revealed autistic bilinguals showed significantly better sustained attention than autistic monolinguals,  $t(25) = -2.28$ ,  $p = .031$ .

*Sustained Attention (Teacher)*. A 2 (diagnostic group) x 2 (language group) ANOVA on teacher-rated sustained attention revealed a significant main effect of diagnostic group,  $F(1, 33) = 26.45$ ,  $p = .000$ ,  $\eta_p^2 = .44$  where TD participants displayed significantly better sustained attention than the autistic participants. There was no significant main effect of language group,  $F(1, 33) = .09$ ,  $p = .758$ ,  $\eta_p^2 = .00$ , nor a significant interaction between language group and diagnostic group,  $F(1, 33) = 1.73$ ,  $p = .198$ ,  $\eta_p^2 = .05$ .

*Interference Control (Parent)*. A 2 (diagnostic group) x 2 (language group) ANOVA on parent-rater interference control demonstrated a significant main effect of diagnostic group,  $F(1, 76) = 13.74$ ,  $p = .000$ ,  $\eta_p^2 = .15$ , where TD participants displayed significantly better interference control than the autistic participants. There was a significant main effect of language group,  $F(1, 76) = 12.07$ ,  $p = .001$ ,  $\eta_p^2 = .13$ , where bilinguals exhibited significantly better interference control than monolinguals. The interaction effect between language group and diagnostic group was significant,  $F(1, 76) = 21.91$ ,  $p = .000$ ,  $\eta_p^2 = .22$ . Post-hoc independent samples t-tests revealed autistic bilinguals showed significantly better sustained attention than autistic monolinguals,  $t(25) = -4.10$ ,  $p = .000$ .

*Interference Control (Teacher).* A 2 (diagnostic group) x 2 (language group) ANOVA on teacher-rated interference control revealed a significant main effect of diagnostic group,  $F(1, 33) = 30.68, p = .000, \eta_p^2 = .48$ , where TD participants displayed significantly better interference control than the autistic participants. However, there was no significant main effect of language group,  $F(1, 33) = .07, p = .785, \eta_p^2 = .00$ , nor an interaction effect between language group and diagnostic group,  $F(1, 33) = .45, p = .503, \eta_p^2 = .01$ .

*Working Memory (Parent).* A 2 (diagnostic group) x 2 (language group) ANOVA on parent-rated working memory demonstrated a significant main effect of diagnostic group,  $F(1, 76) = 5.16, p = .026, \eta_p^2 = .64$ , where TD participants displayed significantly better working memory than the autistic participants. There was no significant main effect of language group,  $F(1, 76) = 2.62, p = .109, \eta_p^2 = .03$ , however, the interaction effect between language group and diagnostic group was significant,  $F(1, 76) = 7.79, p = .007, \eta_p^2 = .09$ . Post-hoc independent samples t-tests revealed autistic bilinguals exhibited better working memory than autistic monolinguals,  $t(25) = -2.20, p = .037$ .

*Working Memory (Teacher).* A 2 (diagnostic group) x 2 (language group) ANOVA on teacher-rated working memory demonstrated a significant main effect of diagnostic group,  $F(1, 33) = 38.26, p = .000, \eta_p^2 = .53$ , where TD participants displayed significantly better working memory than the autistic participants (see Figure 9). However, there was no significant main effect of language group,  $F(1, 33) = .02, p = .886, \eta_p^2 = .00$ , nor interaction between language group and diagnostic group,  $F(1, 33) = .14, p = .707, \eta_p^2 = .00$ .

**Relationship Between Parent and Teacher EF Scores.** A Pearson's  $r$  data analysis on the whole sample (including those with lower consistency index scores) ( $n = 55$ ) revealed strong positive correlations on the following outcome measures, namely: parent and teacher ratings of sustained attention,  $r = .63, p = .000$ ; parent and teacher ratings of flexible switching,  $r = .44, p = .001$ ; parent and teacher ratings of interference control,  $r = .72, p = .000$ ; and parent and teacher ratings of working memory  $r = .40, p = .002$ .

**Comparing EF Performance Across Raters.** Paired samples t-tests on the whole sample ( $n = 55$ ) revealed no significant differences between parents and teachers on any EF outcome measures: parent sustained attention ( $M = 92.44, SD = 15.45$ ) and teacher sustained attention ( $M = 93.15, SD = 17.20$ ),  $t(53) = -.36, p = .715$ ; parent flexible switching ( $M = 94.24, SD = 16.88$ ) and teacher flexible switching ( $M = 93.20, SD = 17.30$ ),  $t(54) = .42, p = .671$ ; parent interference control ( $M = 87.75, SD = 19.29$ ) and teacher interference control ( $M = 89.07, SD = 19.36$ ),  $t(54) = -.68, p = .496$ ; parent working memory ( $M = 94.53, SD = 18.73$ ) and teacher working memory ( $M = 90.51, SD = 17.57$ ),  $t(54) = 1.50, p = .139$ .



## Discussion

The current study investigated the impact of bilingualism in autistic and typically developing children, on a specific set of everyday EF skills measured with parent and teacher reports, in a dual-language environment. All the data were collected in the United Arab Emirates. To our knowledge, this is the first investigation at the interface of bilingualism and autism to use both parent and teacher informant-report measures of EF, and in a group of Arabic-speaking children. The study thus contributes to the diversification of autism research samples; a pressing global issue, in light of the large majority of psychological research that is focused on WEIRD (western, educated, industrial, rich, and democratic) samples (Henrich, Heine, & Norenzayan, 2010; Nielsen, Haun, Kärtner, & Legare, 2017).

The adaptive control hypothesis suggests that interference control, flexible switching, and sustained attention should all be enhanced for bilinguals, especially for those situated in a dual-language context like ours. We also investigated working memory, as a control domain not hypothesized to be impacted by bilingualism. For parent-reports, consistent interaction effects were noted, indicating a bilingual advantage for autistic participants for all four EF abilities relative to monolingual autistic peers. However, this effect of bilingualism was not apparent in teacher-reported EF abilities in the same domains, measured using the same tool.

The consistent finding across parent and teacher reports was a diagnostic effect across most EF outcomes. This indicates autistic children had significantly lower standard scores (poorer EF abilities) relative to TD participants. The presence of this pattern indicates that despite the modest sample size, we did have adequate power to detect diagnostic effects across both EF measures and outcomes. When comparing children's EF performance across raters (full sample), strong correlations were found between parent and teacher reports across all EF outcomes, as well as a lack of significant differences between parent and teacher raters across all EF outcomes.

The finding of widespread bilingual advantage for autistic children across four EF domains should be taken as preliminary evidence and interpreted with caution given the discrepancy of findings between parent and teacher reports. We propose two possible explanations for this discrepancy. First, school and home contexts could encompass different executive demands, resulting in varying perceptions of ability from teachers and parents. Second, our autistic bilingual group is smaller than the other three groups in our study. Small sample size can contribute to greater variability in performance and drive a random effect.

However, the consistency of findings within the rater category (all parent-ratings showing an effect of bilingualism for autistic children) argues against this being the relevant explanation.

We also mark the lack of bilingual advantage for TD children across all outcome variables from both CEFI parent and teacher ratings. Since autistic children generally struggle with executive function tasks like those in our study, this might make it easier to detect bilingual advantages in an autistic than a TD sample. Nonetheless, our autistic participants were mostly cognitively abled, school-aged, proficient bilinguals, living in dual-language contexts and so replications and extensions are required to determine the generalizability of our results.

There are some limitations worth highlighting. First, despite extensive nation-wide efforts to maximize the study's sample size (participant recruitment was supported by 20+ institutions across the UAE), we acknowledge that our bilingual autistic sample is under-sized relative to the other three groups. To address a potential loss in power, we carried out Maxwell and Delaney's (2003) approach to use Type III sums of squares which is resilient to variable group sizes that are subject to comparisons. Second, despite selecting primary caregivers (in the home and school – to fill out parent and teacher reports respectively) who have had extensive and extended quality interactions with our participants, we acknowledge our findings are subject to potential bias in performance, introduced by the informant-report nature of our EF measure. Third, with regards to the task itself, one could argue that certain CEFI items were not applicable to the children on the younger end of the sample spectrum. An example of this is requesting a parent and / or teacher to rate how well a 5-year old child 'manages money' or 'concentrates while reading'. Milestones relating to money management and reading are rarely achieved in this age group. Similarly, some items are not applicable to raters. An example of this is requesting a parent / teacher to rate whether a child 'has good thoughts about everyone'. The statement addresses a child's thoughts, not actions, which can prove difficult for raters to judge. Raters often left items of this nature as unscored or scored as 'never', thus introducing a potential bias.

Using parent ratings, we found an autistic bilingual advantage in the EF areas predicted by the adaptive control hypothesis. However, we also found an autistic bilingual advantage in working memory, which is not an EF domain highlighted by the adaptive control hypothesis. Therefore, it is unclear whether our data lends support to the bilingual advantage prediction by the adaptive control hypothesis.

Another prediction by the adaptive control hypothesis is that some aspects of bilingual language use (e.g., switching tendencies) should correlate with some aspects of EF

performance in the bilingual groups (both autistic and typically developing), regardless of any comparisons with monolinguals. In the current work, only relationships between parent-reported EF and aspects of bilingual language use (e.g., switching tendencies, current language exposure, language proficiency, age of acquisition) were investigated – as outlined in the [thesis-integrated discussion](#). Potential relationships between teacher-reported EF and aspects of bilingual language use were not explored, and should be subjected to future investigations in order to test this prediction.

It is also unclear whether our data extends support to the brain training hypothesis. Using parent ratings, we found bilingual advantages for autistic children in some EF domains highlighted by the brain training hypothesis, but as the current work was not designed to test its full predictions, our conclusions are only partial.

Our data make it very clear, however, that bilingualism does not result in any EF disadvantages for autistic children. Despite concerns from parents and practitioners, we found no evidence that autistic children's executive function abilities are detrimentally affected by learning and using two languages. Together, these findings join a growing body of literature showing that bilingualism does not negatively impact the executive functions of autistic children, and in fact, might mitigate everyday EF difficulties that they face.

### **Declaration of Conflict of Interests**

Authors declare that there is no conflict of interest.

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## **Thesis-integrated investigation**

Following the result of widespread EF advantages for the bilingual autistic group, using parent reports, the purpose of this investigation is to explore potential predictors of parent-reported EF performance. Only bilingual participants are included in this work, collapsed across diagnostic outcomes (both TD and autistic bilinguals). This is primarily because the sample size does not allow for an examination of autistic bilinguals only. This resulted in 28 children ( $M = 9.23$  years,  $SD = 1.44$  years), all of whom have Arabic as their L1 and English as their L2. A series of one-way analysis of variance (ANOVA) confirmed no significant differences between the 2 groups (autistic bilingual, TD bilingual) on non-verbal IQ ( $p = .325$ ), chronological age ( $p = .629$ ), maternal education level ( $p = .287$ ) and maternal continuous years of education ( $p = .865$ ).

Statistical analyses were performed in SPSS Version 24. The data were all found to be normally distributed. This was determined by evaluating kurtosis and skewness values, where absolute figures needed to be less than three times the standard error figures for data to be considered normally distributed. First, correlation analyses were run to explore potential relationships between EF and relevant bilingualism markers (i.e., L2 current language exposure, L2 proficiency, L2 age of acquisition, and L2-switch tendencies). These were identified in my review of the literature on bilingualism and EF as potentially key moderating variables.

First, a Pearson's bivariate correlational analysis revealed a positive correlation between L2 current exposure and: (a) CEFI parent sustained attention,  $r = .419$ ,  $p = .033$ ; (b) CEFI parent interference control,  $r = .403$ ,  $p = .041$ ; (c) CEFI parent flexible switching,  $r = .419$ ,  $p = .053$ . Therefore, increased L2 (English) exposure is associated with better sustained attention, interference control, but not flexible switching. There were no significant

relationships between L2 current exposure and CEFI parent working memory,  $r = .162, p = .429$ .

Second, a Pearson's bivariate correlational analysis revealed a positive correlation between L2 proficiency and CEFI parent sustained attention,  $r = .436, p = .020$ . Therefore, increased L2 proficiency is associated with better sustained attention. There were no significant relationships between L2 proficiency and: (a) CEFI parent interference control,  $r = .255, p = .190$ ; (b) CEFI parent flexible switching,  $r = .227, p = .245$ ; (c) CEFI parent working memory,  $r = .134, p = .497$ .

Third, a Pearson's bivariate correlational analysis revealed no significant relationships between L2 age of acquisition and: (a) CEFI parent sustained attention,  $r = -.169, p = .440$ ; (b) CEFI parent interference control,  $r = -.044, p = .842$ ; (c) CEFI parent flexible switching,  $r = .076, p = .729$ ; (d) CEFI parent working memory,  $r = -.036, p = .869$ .

Finally, a Pearson's bivariate correlational analysis revealed no significant relationships between L2 switch tendencies and: (a) CEFI parent sustained attention,  $r = .299, p = .129$ ; (b) CEFI parent interference control,  $r = .204, p = .307$ ; (c) CEFI parent flexible switching,  $r = .093, p = .645$ ; (d) CEFI parent working memory,  $r = .143, p = .475$ .

Regression assumption testing was then carried out to explore potential predictors of parent-reported EF. First, dependent variables were found to be normally distributed: (a) absolute figures were less than three times the standard error figures, (b) Shapiro-Wilk test was non-significant. Second, no outliers were found. Third, no multicollinearity was detected between predictor variables (correlations  $< 0.7$ ). Fourth, correlations between predictor variables and dependent variables were greater than 0.3. Fifth, the standard residual minimum and maximum values are within -3 to 3 range. Sixth, Cook's distance minimum and maximum values are within -1 to 1 range. Only variables that significantly correlated with the EF domain of interest were considered for regression modelling.

*Sustained Attention.* The following variables were entered into the linear stepwise multiple regression model: (1) L2 Proficiency, (2) L2 Current Exposure. One model was generated by SPSS: **Model 1:** L2 Proficiency (1 Predictor). Model 1 was statistically significant ( $p = .026$ ) with 19.00% of the variance observed in parent-reported sustained attention explained by 'L2 Proficiency'. Therefore, L2 proficiency was a significant predictor of parent-reported sustained attention. Therefore, a greater proficiency in L2 increases the probability of better parent-reported sustained attention.

*Interference control.* Only variables that significantly correlated with CEFI parent interference control were considered for regression modelling. In this case, only L2 current

exposure was considered. One model was generated by SPSS: **Model 1: L2 Current Exposure** (1 Predictor). Model 1 was statistically significant ( $p = .041$ ) with 16.20% of the variance observed in parent-reported interference control explained by 'L2 Current Exposure'. Therefore, 'L2 Current Exposure' was a significant predictor of parent-reported interference control. Therefore, a greater proficiency in L2 (English) increases the probability of better parent-reported interference control.

### **Thesis-integrated discussion**

In line with my thesis aims, I have explored the impact of bilingualism on the EF skills of autistic children, using a carefully selected informant report measure of EF that captures EF abilities over a period of time, and in daily-type of contexts. I have shown, once again, that bilingualism does not negatively impact the executive functions of autistic children, and that in fact, it might positively influence EF. A possible explanation for a bilingual advantage for autistic children (especially in parent-reported EF, as advantages were widespread) but not for TD children, is that there is more room for EF improvement in autistic children. Since autistic children generally struggle with executive function tasks like those in our study, this might make it easier to detect bilingual advantages in an autistic than a TD sample. Another possible explanation is that the effect of bilingualism in autistic children might be one of cognitive preservation, rather than cognitive advantage per se. Here, bilingualism may compensate for typical EF skills in autism by mitigating difficulties across EF domains. This explanation is in line with cognitive reserve preservation effects of bilingualism evidenced in old age (Bak et al. 2014) and is supported by the findings of Gonzalez-Barrero and Nadig (2017) and Peristeri et al. (2020) which report mitigating effects of bilingualism on flexible switching difficulties in autistic children.

The autistic bilingual advantage revealed by parent reports, but not teacher reports, might reflect a difference in the executive demands elicited within each environment (home versus school), and therefore, differences in informant perspectives. I have also found that second language proficiency predicted parent-reported sustained attention (a greater proficiency in L2 increases the probability of better parent-reported sustained attention), and second language current exposure predicted parent-reported interference control (a greater exposure to L2 increases the probability of better parent-reported interference control). However, I must recognize the same model might not work for a different data set with the same measures, given my modest sample size.

In summary, both L2 proficiency and L2 current exposure were predictors of parent-reported EF – however L2 age of acquisition and L2-Switch (the tendency to switch from L1 to L2) were not. It is possible that I did not find relationships with language switching (L2-Switch) due to a limitation with the BSWQ language switching measure; that is, the BSWQ might not have captured the type of language switches that are most demanding for EFs. As highlighted earlier, the ACH distinguishes between three types of language switching contexts: single, dual, and dense. While dense contexts place minimal demand on EF (i.e., speakers in this context are free to use either language freely), dual contexts place maximum demand on EF (i.e., one language at a time which exercises cognitive control capacities). The BSWQ fails to clearly differentiate between dense and dual language switching environments, possibly resulting in a lack of relationships to parent-reported EFs.

A key finding across my combined investigations of the effects of bilingualism on EF using a multidimensional approach relates to diagnostic group differences. Autistic groups were generally impaired on almost every EF measure, relative to TD groups. However, using an analysis that averages EF performance across a group can prove problematic, given that autistic individuals are highly variable in terms of their abilities and disabilities. This variability in my results across types of measurement may directly relate to the limitation of this kind of design, comparing two group means.

Therefore in addition to the group comparison analyses carried out in Chapters 3 and 4, Chapter 5 (my third and final research investigation) aims to: (a) introduce a multiple case series approach to investigate patterns of EF strengths and weaknesses in my autistic participants (regardless of their language status), relative to TD groups, and (b) examine potential relationships between EF performance (directly-assessed and informant-report EF abilities) and autistic features. Deploying a linguistically-diverse sample for this analysis is likely, if anything, to increase the range of EF abilities demonstrated and therefore prove particularly fruitful in this investigation of heterogeneity.

# Chapter 5: Executive functions: Exploring individual differences in performance and relationships to autism features

## 1. Introduction

### A. Executive functions in autism: A multiple case-series approach

Behavioral and genetic data lend support to the heterogeneity of autism, suggesting no single neurobiological or cognitive feature is enough to explain all the cases of autism (Happé, Ronald, & Plomin, 2006; Minshew, Goldstein, & Siegel, 1997; Viding & Blakemore, 2007). Similarly, neurological data demonstrate a non-typical process for functional specialization in autism (Gilbert, Meuwese, Towgood, Frith, & Burgess, 2009; Pierce, Miller, Ambrose, Allen, & Courchesne, 2001) which may translate to complex and individualistic structures of strengths and weaknesses for autistic individuals (Gilbert et al., 2009).

As a result, autistic people have often been characterized as having a “spiky profile” of widely varying strengths and weaknesses on cognitive assessment batteries (Bölte, Dziobek, & Poustka, 2009; Happé, 1994; Scheuffgen, Happe, Anderson, & Frith, 2000). As such, it has been argued that significant differences between groups are not indicative of impaired performance in all participants, just as much as non-significant group differences are not indicative of intact performance in all participants.

One factor that contributes to the inconsistent findings in the literature surrounding the nature and pattern of executive dysfunction in autistic children, is the method of analysis. Most studies investigating cognitive deficits employ a group differences design that compares the average performance of autistic participants with the average performance of TD participants. On one hand, often studies using a group differences design indicate that autistic children are impaired across several EF domains with significant differences apparent between autistic and TD groups (Happé, Booth, Charlton, & Hughes, 2006; Liss et al., 2001; Semrud-Clikeman, Walkowiak, Wilkinson, & Butcher, 2010). On the other hand, some studies have shown no differences between autistic and TD groups (Kaland, Smith, & Mortensen, 2008; Van Eylen et al., 2011).



Regardless of the effects found (or lack thereof) between TD and autistic participants, such studies fail to investigate the differences between autistic individuals. A significant limitation of group-level analysis is with respect to “averaging artifact” (Shallice & Evans, 1978). Findings on a group-level do not offer a description of, or insight into the performance of any single member within the group. This method of analysis can be especially problematic in autism research where there are large individual differences in EF task performance (Geurts, Sinzig, Booth, & Happ, 2014; Johnston, Madden, Bramham, & Russell, 2011; Pellicano, 2010).

One option to overcome this obstacle is a methodology called multiple case series analysis (MCSA; Hill & Bird, 2006; Towgood, Meuwese, Gilbert, Turner, & Burgess, 2009). By incorporating analysis at the level of the individual, the domains in which a given individual displays a varied performance range can be revealed. This may be of particular interest when applied to a sample such as ours, in which some autistic children’s cognitive development has been shaped by a bilingual environment, potentially increasing the range of scores even further than in a monolingual autistic group.

A limited number of studies have investigated EF performance in autistic individuals using a multiple case series approach. The following brief review only reports on EF outcomes similar and relevant to my investigation.

One study with autistic children (Maria Luz et al., 2014) and two with autistic adults (Baez et al., 2012; Towgood et al., 2009) investigated executive function performance using both group and MCSA methodology. In the first study, 19 autistic children were matched to 19 TD children on age, gender, and intelligence. Using group analysis, the authors revealed intact / sub-normal autistic performance for directly-assessed working memory and flexible switching. When MCSA was run, however, flexible switching was found to be sub-normal but working memory was ‘very enhanced’ (>2 SD from the TD mean). In the second study by Baez et al. (2012), 15 autistic adults were matched to 15 TD adults on age, gender, and years of formal education. Using group analysis, the authors reported sub-normal interference control and working memory - but impaired flexible switching. On the other hand, the majority of autistic participants performed at a significantly lower level relative to TD peers, across EF domains – using MCSA. The third study by Towgood and colleagues matched 21 autistic adults to 22 autistic TD peers on age and IQ. Group analysis revealed autistic deficits in flexible switching, whereas MCSA revealed variability with some participants performing at ‘very enhanced’ and ‘very impaired’ ranges. Overall, the findings indicate a level of

variability revealed by MCSA that was not reflected when the data were analyzed at the group-level.

## **B. Executive functions in relation to autism features**

As well as investigating variability in EF within our autistic sample, this individual level analysis offers the chance to investigate whether EF abilities vary with autistic profiles. The following section highlights relevant literature examining the link between the specific executive function processes selected for inclusion in this thesis, and diagnostic features of autism: the social and communication domain, and the repetitive and restricted behaviors domain (*DSM-5*; American Psychiatric Association, 2013). The review is not systematic, but attempts to focus on relatively well-powered studies (where available), investigating more cognitively-abled children and young people.

*a) Restricted and repetitive behaviours (RRBs).* Clinical expressions of this feature include inflexible routines (e.g., insisting on taking the same route to school or work every day), stereotypical motor movements (e.g., hand flapping), opposition to change, obsessions, and challenges with adapting to new situations.

*RRBs and flexible switching.* The majority of studies have focused on flexible switching in relation to RRBs. A study by Lopez, Lincoln, Ozonoff, and Lai (2005) reported a strong positive correlation between directly-assessed flexible switching and RRBs (both clinically-assessed and directly observed) in a sample of young autistic adults. Kenworthy, Black, Harrison, Della Rosa, and Wallace (2009) also provided support for this finding using the same measures of RRBs and an EF-informant report measure, in a sample of children aged 6 to 17 years. A more recent study by D'Cruz et al. (2013) also demonstrated a positive correlation between directly-assessed flexible switching and parent-reported RRBs in a group of adolescent autistic individuals. Similarly, Yerys et al. (2009) reported a positive correlation between directly-assessed flexible switching and clinically-assessed RRBs.

However, there have also been null findings concerning the relationship between flexible switching and RRBs. In a group of autistic adolescents, there was no direct association between flexible switching and parent-report RRBs (Jones et al., 2018). Similarly, Cantio, Jepsen, Madsen, Bilenberg, and White (2016) found no evidence that directly-assessed flexible switching predicted RRBs (assessed with direct observation, parent reports and parent interview) in a group of autistic children. In summary, the evidence base regarding the relationship between flexible switching and RRBs is contradictory, with findings for and

against a link. Differences in findings can possibly be explained by differences in how flexible switching (degree of structure in assessments) and RRBs feature are measured, in addition to differences in sample size (Brunsdon & Happé, 2014; Eylen, Boets, Steyaert, Wagemans, & Noens, 2015).

*RRBs and Working memory.* In the same study reported above, Lopez et al. (2005) found working memory had a significant positive correlation with their RRBs composite variable. Sachse et al. (2013) also reported a significant positive correlation between directly-assessed working memory and directly-observed RRBs in a group of adolescent and young adult autistic individuals. Similarly, Rabiee, Vasaghi-Gharamaleki, Samadi, Amiri-Shavaki, and Alaghband-Rad (2020) reported a significant positive correlation between directly-assessed working memory and parent-reported RRBs, in a group of autistic children and adolescents. Null findings, however, are also present in the literature.

Joseph and Tagerflusberg (2004) failed to find associations between directly-assessed working memory and the directly observed RRBs, in a group of autistic children aged 5 to 14 years. Similarly, van den Bergh, Scheeren, Begeer, Koot and Guerts (2014) found no associations between parent-reported working memory and directly-observed RRBs in a group of children aged 6 to 18 years.

Research on the relationship between working memory and RRBs remains contradictory and too limited to draw solid conclusions. Overall, investigations in the literature have included a wide range of autism sub-types, feature profiles, ages, executive tasks, and measures of autism features; all of which can yield mixed results.

*RRBs and Sustained Attention.* A study by Shiri et al. (2015) reported a positive correlation between impaired sustained attention (directly-assessed) with directly-observed RRBs, in a group of autistic children aged 5 to 12 years. Our knowledge, however, about sustained attention (the ability to direct attention to relevant stimuli while ignoring irrelevant information or distractions) in relation to RRBs in autism remains very limited as other studies have focused on other types of attention.

*RRBs and Interference Control.* Using the Stroop task in a sample of young autistic adults, Lopez et al. (2005) reported that impaired response inhibition (directly-assessed) had a significant positive correlation with RRBs (both directly observed and clinically-assessed). From a parent-report measure of EF in a sample of school-aged autistic children, Boyd, McBee, Holtzclaw, Baranek, and Bodfish (2009) also reported a significant positive correlation between impaired response inhibition and parent-reported RRBs. These are two out of several studies that target the ‘response inhibition’ aspect of inhibition in relation to

RRBs. The current work, however, targets the ‘interference control’ type of inhibition which has not been properly investigated to date in relation to autism features.

**b) *Social differences. Social differences and flexible switching.*** In a group of autistic children aged 6 to 17 years, Kenworthy et al. (2009) provided support for a strong positive correlation between parent-report flexible switching and social interaction impairments that were clinically-assessed and directly observed. There is more support for null findings, however. Yerys et al. (2009) found no correlation between directly-assessed flexible switching and social domains (clinically-assessed) in a group of autistic children aged 6 to 14 years. Similarly, D’Cruz et al. (2013) demonstrated no correlation between directly-assessed flexible switching and social skills (clinically-assessed) in a group of adolescent autistic individuals. A more recent study by Jones et al. (2018) investigating a group of autistic adolescents, failed to find a direct association between directly-assessed flexible switching and an informant-report of social communication.

In summary, there is unlikely to be a link between flexible switching and social domains in autism when using experimental tasks. Our knowledge remains limited in the absence of investigations using parent-report measures to capture EF in a more ecologically valid sense, in relation to the social domain of autism.

***Social differences and working memory.*** Rabiee et al. (2020) reported a significant positive correlation between directly-assessed working memory and social interaction (assessed with informant-report measures), in a group of autistic children and adolescents. Null findings, however, are also present in the literature. Joseph and Tagerflusberg (2004) failed to find associations between directly-assessed working memory and directly observed social interactions, in a group of autistic children aged 5 to 14 years. In summary, the evidence base regarding the relationship between working memory and the social domain of autism is too limited to infer relationships or a lack thereof. Both directly-assessed and informant-report investigations of EF are warranted to further our understanding of potential links to autism features.

***Social differences and sustained Attention.*** Shiri et al. (2015) reported that poorer performance in sustained attention (directly-assessed) was significantly associated with social interaction difficulties (assessed with informant-report measures) in a group of autistic children aged 5 to 12 years. A study by Kenworthy et al. (2009) further supported this correlation, and reported that better sustained attention performance (directly-assessed) was associated with fewer social difficulties (both clinically-assessed and directly observed) in a sample of autistic children aged 6 to 17 years. As mentioned earlier, our knowledge about

sustained attention in relation to features in autism remains very limited as other studies have focused on other types of attention (shifting attention and shared attention).

*Social differences and interference control.* Knowledge about inhibition processes in relation to social domains in autism is scarce. A study by Bishop and Norbury (2005) reported no evidence for any specific link between poor response inhibition (directly-assessed) and social domains (both clinically-assessed and directly observed) in a group of autistic children. A more recent study by Schmitt et al. (2018) echoed these findings in a group of autistic children who were directly assessed on response inhibition and clinically-assessed as well as directly observed, on social communication. However, the authors highlight that the time duration between administration of the task and clinical measures could have played a role in the findings, as longer intervals between administration could reduce the strength of associations. These are two out of very few studies that target the ‘response inhibition’ aspect of inhibition in relation to social domains in autism. The current work, however, targets the ‘interference control’ type of inhibition (rationale addressed in Chapter 1) which has not been properly investigated to date in relation to autism features.

This review thus indicates the importance of examining individual variability in autistic samples, rather than purely relying on group designs to gain EF insights. Additionally, the review highlights some potential relationships between EF and autism features that would benefit from further investigation – especially in the understudied areas of interference control and sustained attention. My linguistically diverse sample, while modest in size, but rich in linguistic variability (monolingual and bilingual groups combined), lends richness and provides a particularly fertile ground for such investigations.

## **2. Research questions and hypotheses**

**R1.** Does multiple case series analysis reveal findings that are not detected in the traditional group-level analysis deployed in Chapters 3 (directly-assessed EF measures) and 4 (informant-report EF measures)?

**R2.** Is there evidence for a spiky profile of EF performance in our autistic sample?

**R3.** Is there a significant relationship between EF performance and diagnostic features of autism?

For R1, guided by the literature findings on MCSA and the established heterogeneity in autism, I hypothesize that taking a multiple case series approach will reveal a pattern of variability that cannot be revealed with group-level analysis. I have no specific hypothesis

relating to my exploratory analysis of the relationship between EF measures and autism features as the existing literature is largely inconclusive.

### 3. Participants

Twenty-seven autistic participants contributed data to this analysis. The whole autistic sample (monolinguals and bilinguals) is pooled for this analysis. Details of participant characteristics are presented in Table 9.

**Table 9.** Participant demographics by language group: Multiple case series analyses

	Monolingual Autistic (N=9) M (SD)	Bilingual Autistic (N=13) M (SD)
Participant age ( <i>months</i> )	101.00 (23.37)	119.23 (25.03)
CPM ( <i>grade</i> )	2.56 (1.42)	3.15 (1.67)
Paternal education level	5.50 (1.04)	5.71 (1.38)
Paternal education ( <i>years</i> )	16.17 (2.13)	17.71 (3.20)
Maternal education level	5.43 (1.71)	5.13 (1.64)
Maternal education ( <i>years</i> )	16.14 (2.03)	16.62 (3.33)
Gender (M/F)	7/2	8/5

*Note.* M = mean; SD = standard deviation; TD = typically developing; CPM = nonverbal IQ composite score from the Colored Progressive Matrices (IQ grade): (Grade 1 = intellectually superior (score lies at or above the 95<sup>th</sup> percentile for individuals of that age group); Grades 2 and 3 = definitely above average (score lies at or above the 75<sup>th</sup> percentile for individuals of that age group); Grades 4 and 5 = intellectually average (score lies between the 25<sup>th</sup> and 75<sup>th</sup> percentile for individuals of that age group); Grades 6 and 7 = intellectually below average (score lies at or below the 25<sup>th</sup> percentile for individuals of that age group); Grade 8 = intellectually impaired (score lies at or below the 5<sup>th</sup> percentile for individuals of that age group)).

### 4. Materials

*EF profiles.* The MCSA analysis in this study draws on data from both directly-assessed and informant-report measures of EF. Directly-assessed EF measures include the Simon Task (interference control), the PVT (sustained attention), the DCCS Task (flexible switching), the SOPT task (working memory) Details on task properties and procedures are thoroughly addressed in Chapter 2 ([Section 2.5b](#)). Informant-report measures of EF include CEFI Parent and CEFI Teacher reports (cross-reference), with quality indicators like the consistency index indicating how consistent / inconsistent the rater's responses are.

*Autism feature profiles.* The Social Responsiveness Scale-2 (SRS-2), made up of 65-items, with each item rated on a 4-point scale, was administered to teachers. It targets the social communication and restricted and repetitive behaviors features, with higher scores indicating more pronounced clinical difficulties for children. Details on task properties and procedure are thoroughly addressed in Chapter 2 ([Section 2.5f](#)).

## 5. Data analyses

*EF profiles.* I conducted a multiple case series analysis, similar to that of Towgood and colleagues, but I explored different degrees of variability (i.e., 1SD and 2SD from the TD mean). First, I computed TD means and SD.

I then identified autistic participants whose directly-assessed EF scores (i.e., reaction times, mean errors, etc.) were greater than the TD mean (signaling poorer performance relative to the TD mean) and less than the TD mean (signaling better performance relative to the TD mean) at 1SD and 2SD variability. Table 10 illustrates the ranges of autistic performance and their corresponding distance and position from the TD mean.

**Table10.** Ranges of autistic performance and their corresponding distance and position from the TD mean

Performance range	Corresponding distance and position from TD mean
Very Enhanced	>2SD below TD Mean indicates much better autistic performance
Enhanced	>1SD below TD Mean indicates better autistic

	performance
Normal	Equivalent to TD Mean ( <b>within 2SD</b> )
Impaired	<b>&gt;1SD above</b> TD Mean indicates poorer autistic performance
Very Impaired	<b>&gt;2SD above</b> TD Mean indicates much poorer autistic performance

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Therefore, a total of 5 performance ranges were identified: ‘very impaired’, ‘impaired’, ‘very enhanced’, ‘enhanced’, and ‘normal’. The degree of intra-individual variability is indexed by the combination of performance ranges. For example, an autistic participant that displays a mix of ‘enhanced’ and ‘normal’ performance across three EF measures, indicates some intra-variability within their EF profile. This intra-variability is not, however, a marked one. In my work, I adopt the following threshold: the presence of three different levels of performance ranges constitutes marked variability (i.e., spiky performance). In other words, the spiky performance is indexed by the presence of ‘enhanced or very enhanced’ + ‘impaired or very impaired’ + ‘normal’ levels of performance.

It is worth noting that my threshold of a spiky performance (marked variability) sets a more rigorous threshold for variability than some common thresholds adopted in MCSA research on autism (e.g., Gonzalez-Gadea et al., 2013; Maria Luz et al., 2014). The study by Luz et al. (2014), for example, reported ‘marked’ inter-individual variability in their autistic sample to refer to the presence of ‘normal’ and ‘very enhanced’ performance (two levels of performance) in their autistic group. In my view, this is a discounted view of variability. The other factor here is that spikiness is not about the range of EF profiles represented in the data, it is about the range within a single participant.

*EF and autism features.* To investigate potential relationships between EF domains (interference control, sustained attention, flexible switching, and working memory) and autism features, I conducted a Pearson’s correlation analysis between: (a) directly-assessed EF scores (from Chapter 3) and SRS T-Scores corresponding to autism features, namely social communication impairment (SCI T-Score) and restricted repetitive behaviors (RRB T-Score), (b) informant-report EF (parent and teacher) scores (from Chapter 4) and SCI T-Score and RRB T-Score. Only parent reports with a consistency index > 75 (CEFI quality

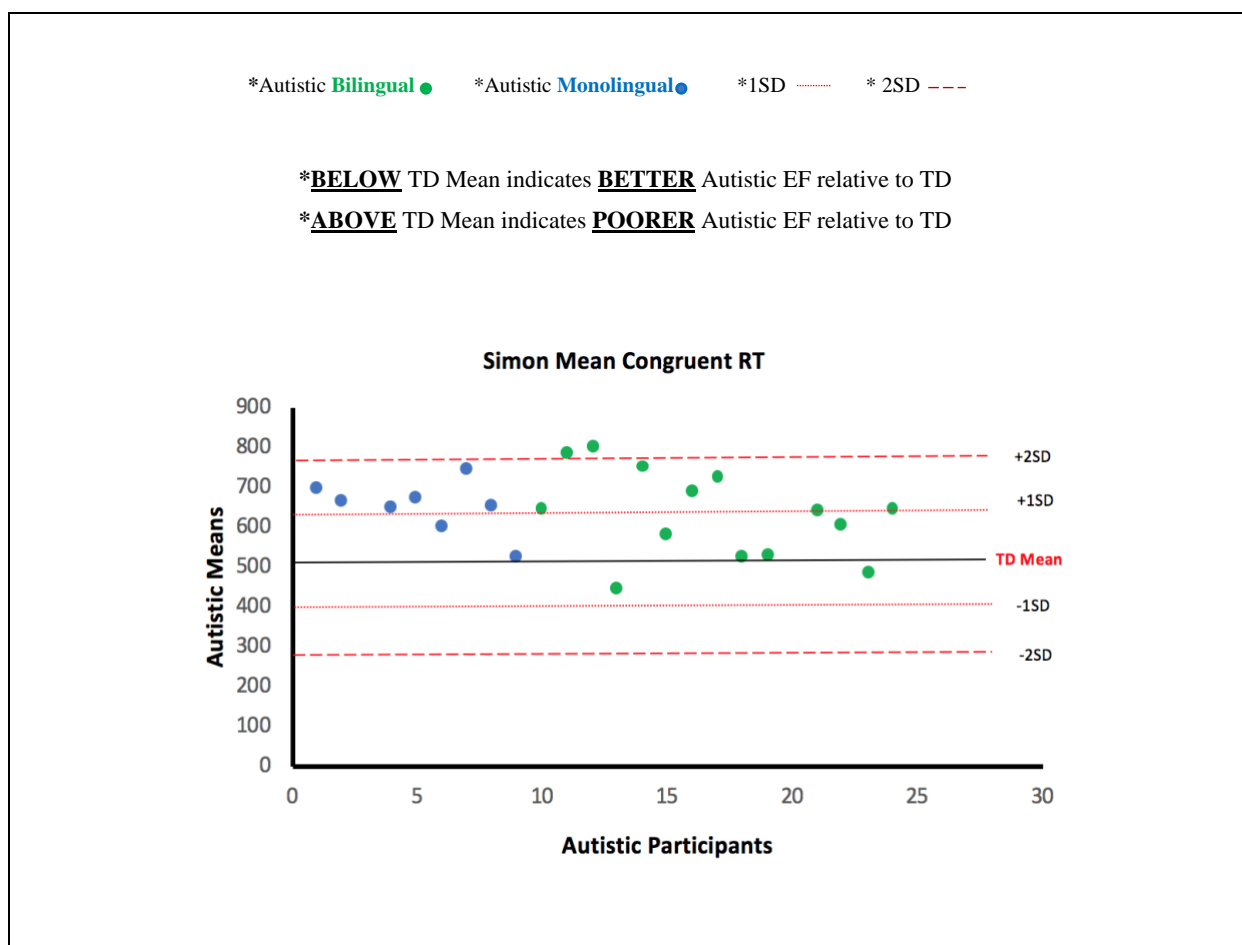


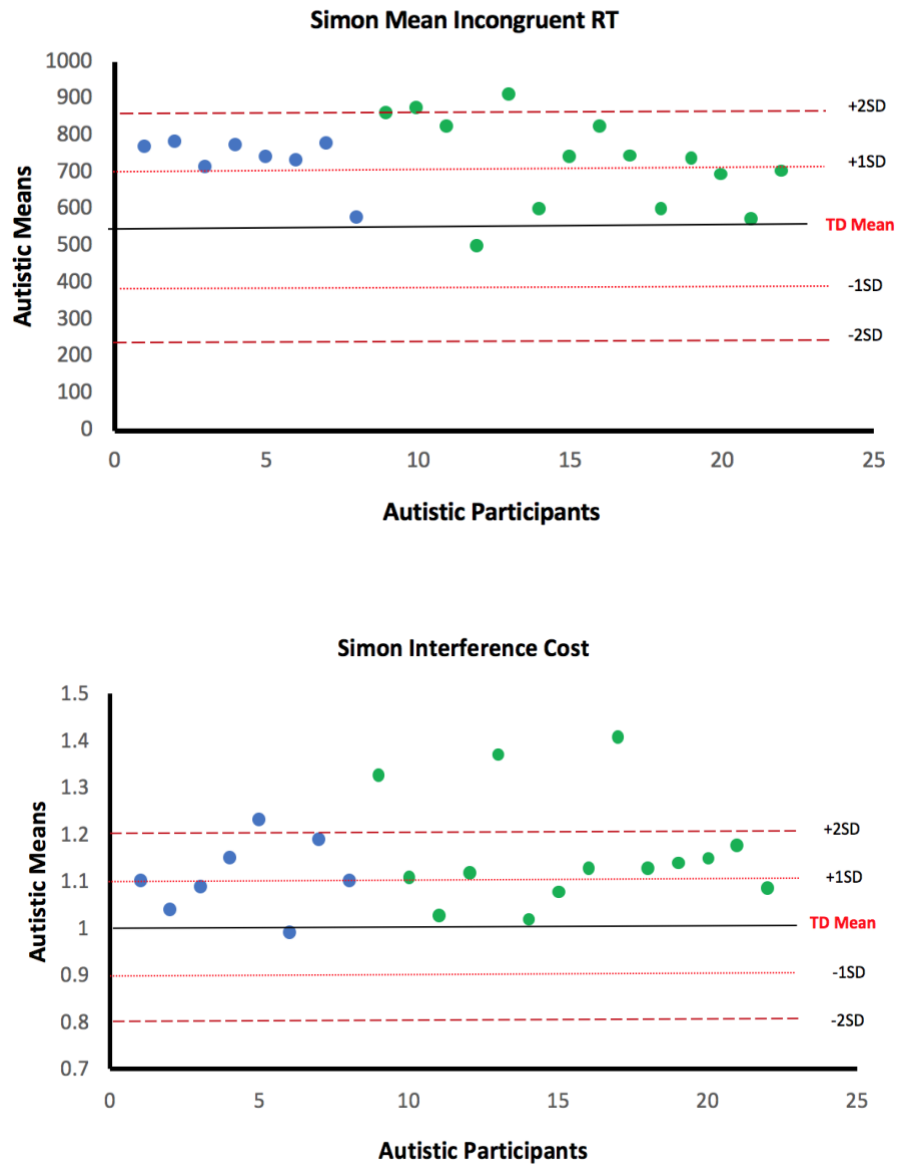
threshold) were included in the analysis. Sample size varied across analyses / sub-analyses due to missing data. The number of contributing participants is provided for every analyses / sub-analyses below.

## 6. Results

### A. Intra-individual differences: Directly-assessed EF performance

Figures 2.3-2.6 visualize the autistic individual performance for every EF outcome variable, plotted relative to the TD mean.



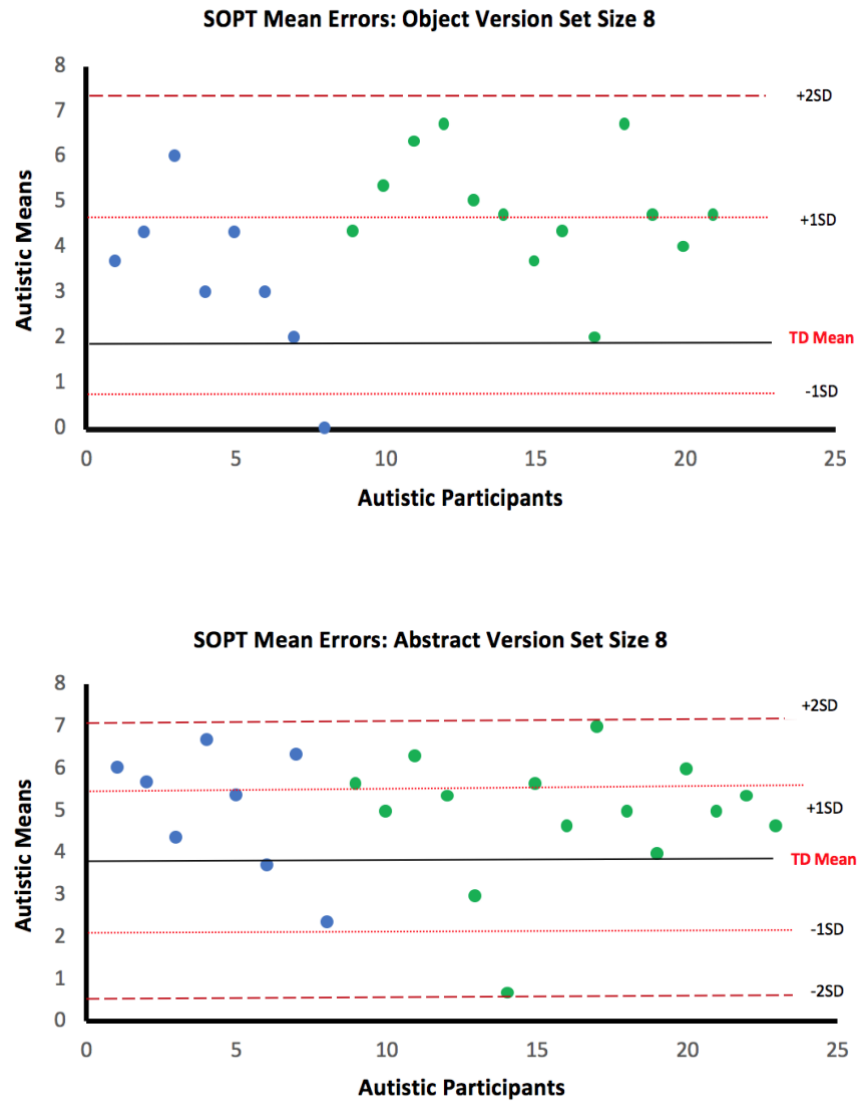


**Figure 2.4.** Autistic group interference control performance visualization from the TD mean.

\*Autistic Bilingual ● \*Autistic Monolingual ● \*1SD - - - \* 2SD - - -

\***BELOW** TD Mean indicates **BETTER** Autistic EF relative to TD

\***ABOVE** TD Mean indicates **POORER** Autistic EF relative to TD

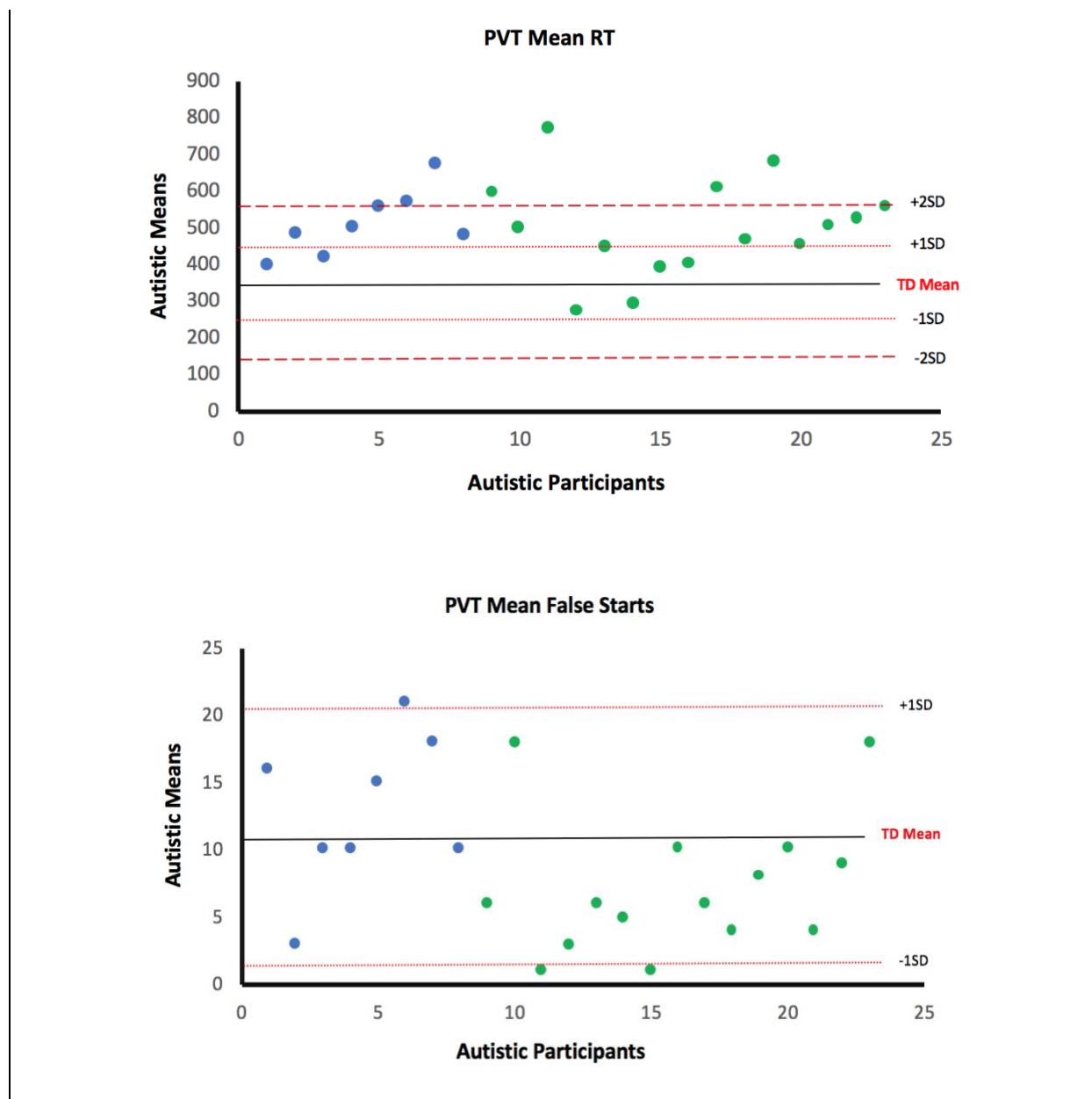


**Figure 2.5** Autistic group working memory performance visualization from the TD mean.

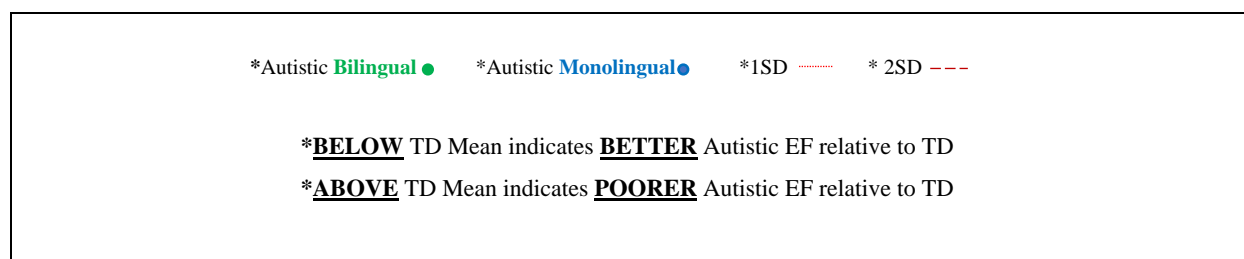
\*Autistic Bilingual ●    \*Autistic Monolingual ●    \*1SD .....    \* 2SD ----

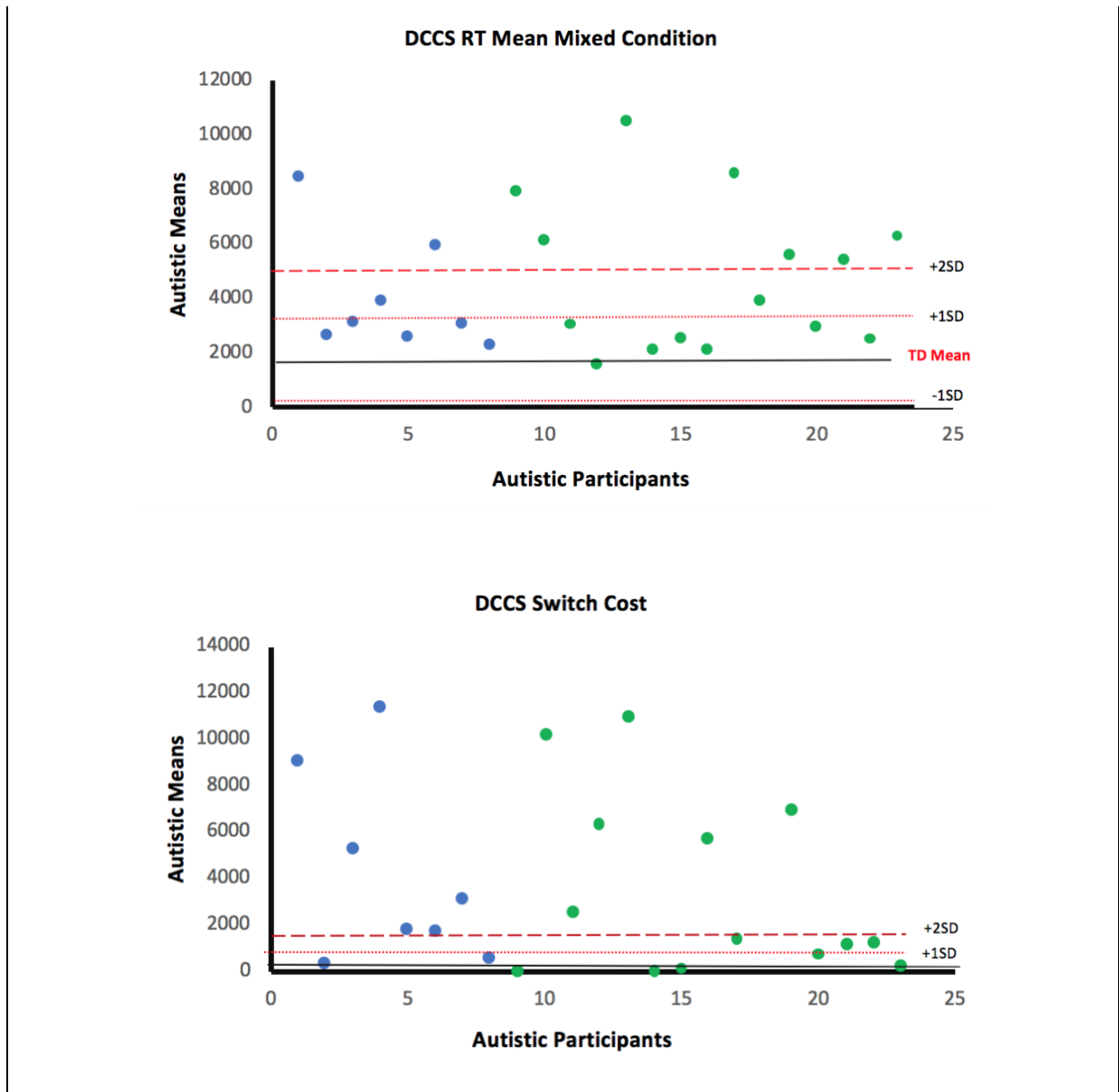
\***BELOW** TD Mean indicates **BETTER** Autistic EF relative to TD

\***ABOVE** TD Mean indicates **POORER** Autistic EF relative to TD



**Figure 2.6** Autistic group sustained attention performance visualization from the TD mean





**Figure 2.7.** Autistic group flexible switching performance visualization from the TD mean

Figure 2.8 depicts the amount of variation across EF tasks obtained for each autistic participant at 1SD and 2 SD thresholds respectively from the TD mean. Every row represents a single autistic participant's individual variability across a range of EF outcomes, with SD scores recorded for every EF outcome variable. These SD scores were converted into absolute scores and summed across nine EF outcomes to compute an 'individual variability score' for each autistic participant.

Very Enhanced	>2SD <b>below</b> TD Mean indicates much better performance
Enhanced	>1SD <b>below</b> TD Mean indicates better performance
Normal	Equivalent to TD Mean
Impaired	>1SD <b>above</b> TD Mean indicates poorer performance
Very Impaired	>2SD <b>above</b> TD Mean indicates much poorer performance

	I-E	I-CRT	I-INCRT	WM-O8	WM-A8	SA-RT	SA-FS	FS-RTM	FS-SWCT
A1	-0.028	-1.176	-1.099	-0.395	-1.326	0.293	-0.526	-3.65	-3.543
A2	0.623	-1.733	-1.182	-0.711	-1.121	-0.67	0.899	0.35	0.682
A3	0.08	-0.691	-0.604	-1.51	-0.29	0.072	0.131	0.035	-1.691
A4	-0.571	-0.913	-1.115	-0.074	-1.741	-0.914	0.131	-0.5	-4.642
A5	-1.44	-0.205	-0.847	-0.711	-0.91	-1.565	-0.416	0.428	-0.021
A6	1.166	-1.631	-0.788	-0.074	0.118	-1.704	-1.074	-1.916	0.023
A7	-1.006	-0.711	-1.141	0.403	-1.53	-2.889	-0.745	0.081	-0.68
A8	-0.028	0.593	0.543	1.36	0.949	-0.624	0.131	0.6	0.584
A9	-2.527	-0.64	-1.836	-0.711	-1.121	-1.983	0.57	-3.29	0.847
A10	-0.137	-2.087	-1.962	-1.189	-0.706	-0.833	-0.745	-2.056	-4.078
A11	0.732	-2.198	-1.526	-1.668	-1.53	-4.039	1.118	0.1	-0.386
A12	-0.245	1.382	1.189	-1.831	-0.91	1.745	0.899	1.146	-2.241
A13	-2.962	-0.822	-2.272	-1.031	0.534	-0.31	0.57	-5.067	-4.457
A14	0.84	-0.043	0.351	-0.874	1.979	1.501	0.68	0.745	0.832
A15	0.188	-1.075	-0.847	-0.395	-1.121	0.374	1.118	0.448	0.779
A16	-0.354	-1.449	-1.526	-0.711	-0.501	0.27	0.131	0.735	-1.936
A17	-3.396	0.552	-0.872	0.403	-1.946	-2.145	0.57	-3.69	0.197
A18	-0.354	0.482	0.317	-1.831	-0.706	-0.473	0.789	-0.496	-29.342
A19	-0.463	-0.6	-0.797	-0.874	-0.085	-2.993	0.351	-1.687	-2.534
A20	-0.571	-0.236	-0.453	-0.553	-1.326	-0.357	0.131	0.178	0.475
A21	-0.897	0.997	0.577	-0.874	-0.706	-0.926	0.789	-1.531	0.252
A22	0.08	-0.65	-0.537	X	-0.91	-1.193	0.241	0.511	0.223
A23	X	X	X	X	-0.501	-1.53	-0.745	-2.131	0.73

**Figure 2.8.**  $N = 23$ . Amount of variation across EF tasks obtained for each autistic participant (intra-individual variability).

*Note.* I-E = Interference Control (Effect); I-CRT = Interference Control (Mean RT on Congruent Trials); I-INCRT = Interference Control (Mean RT on Incongruent Trials); WM-O8 = Working Memory (Mean Errors Set Size 8 Object Version); WM-A8 = Working Memory (Mean Errors Set Size 8 Abstract Version); SA-RT = Sustained Attention (Mean RT); SA-FS = Sustained Attention (Mean False Starts); FS-RTM = Flexible Switching (Mean RT on Mixed Trials); FS-SWCT = Flexible Switching (Switch Cost).

With respect to participants (rows A1 to A23), this analysis clearly shows: (a) no evidence of very enhanced autistic EF performance, (b) the vast majority of autistic EF performance is in the normal range, and (c) only a handful of autistic children show what look like spiky profiles, namely, A6, A11, A12. Overall, while there is some variability (each participant has a mix of two performance ranges across EF tasks), it is not a marked one (i.e., such as profiles A6, A11, A12, depicting three levels of performance). Therefore, this analysis does not support evidence of spiky EF profiles in autistic children.

With respect to EF outcome variables (columns I-E to FS-SWCT), this analysis clearly shows: (a) more than 50% of the “very impaired” performance recorded corresponded to flexible switching outcome variables, (b) with the exception of “flexible switching – switch cost”, every EF outcome variable produces one or two instances of enhanced performance, (c) there are no instances of outcome variables producing “very enhanced performance”, (d) no outcome variable produces more than two instances of enhanced performance, (e) the spikiest profiles from an EF outcome variable perspective correspond to interference control and sustained attention, as both include multiple instances of enhanced, normal and very impaired performance, (f) working memory is more consistently associated with normal / mildly impaired performance.

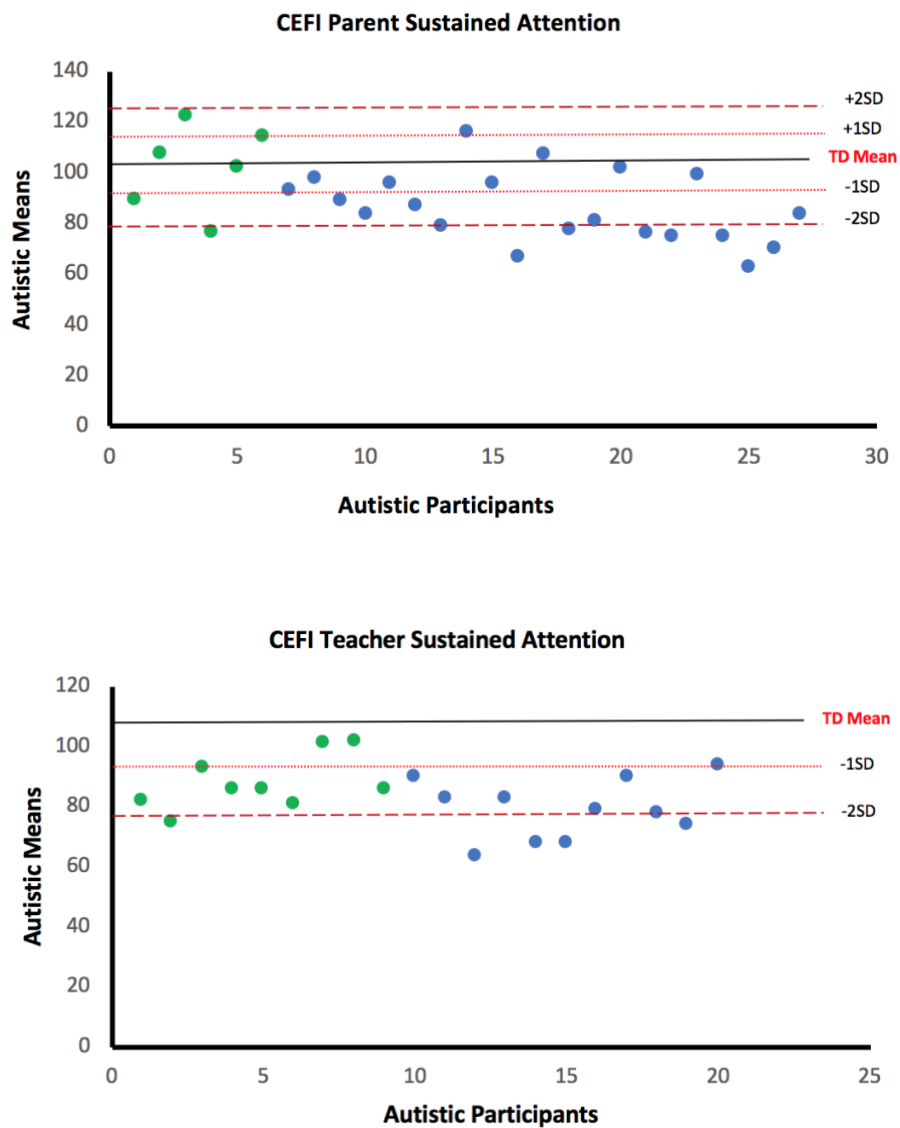
## B. Intra-individual differences: Informant-report EF performance

Figures 2.9-3.2 visualize the autistic individual performance for every EF outcome variable, as measured by parent and teacher reports, plotted relative to the TD mean.

\*Autistic **Bilingual** ●    \*Autistic **Monolingual** ●    \*1SD ———    \*2SD ---

\***BELOW** TD mean indicates **POORER** autistic EF relative to TD

\***ABOVE** TD mean indicates **BETTER** autistic EF relative to TD



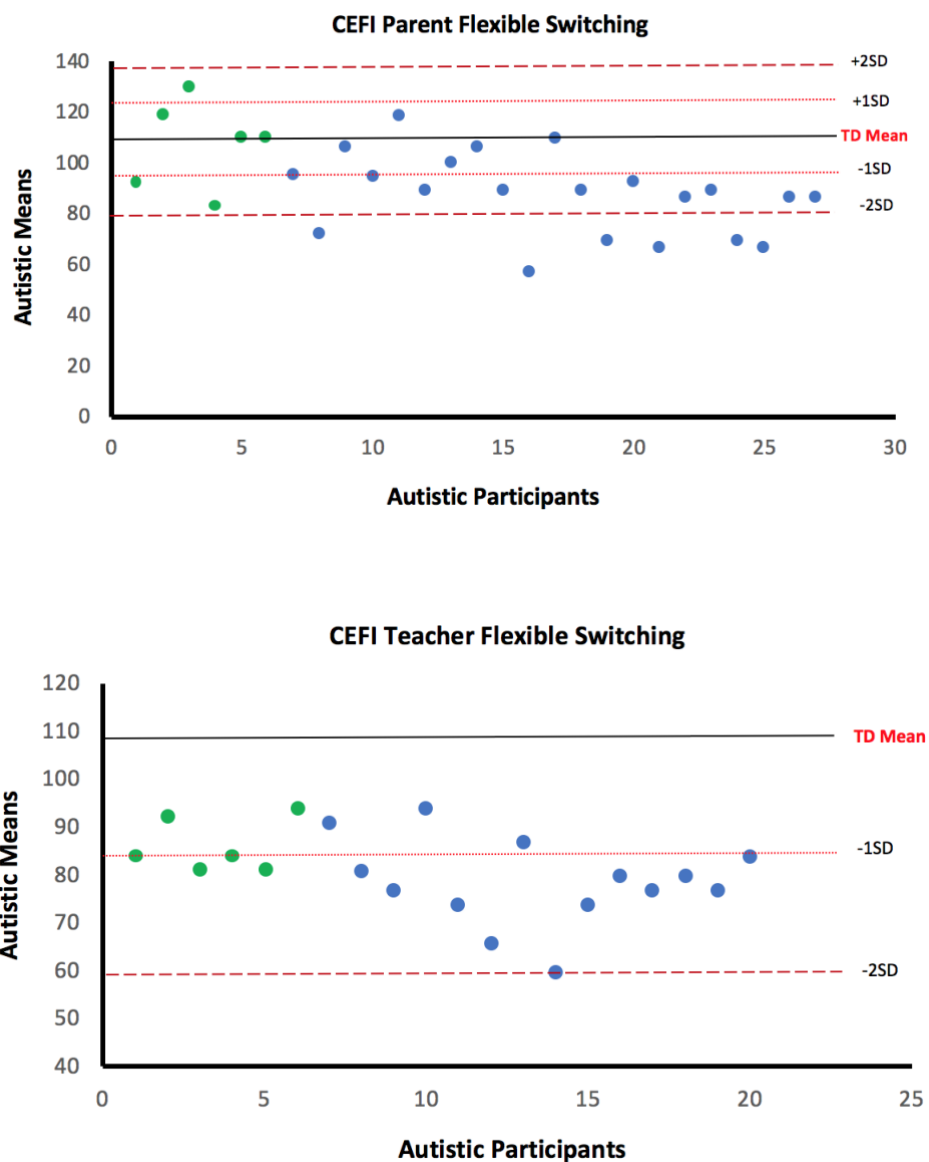
**Figure 2.9** Parent-reported sustained attention: A visualization of autistic performance relative to the typically developing mean

\*Autistic Bilingual ● \*Autistic Monolingual ● \*1SD - - - \* 2SD - - -

**BELLOW** TD mean indicates **POORER** autistic EF relative to TD

\***ABOVE** TD mean indicates **BETTER** autistic EF relative to TD



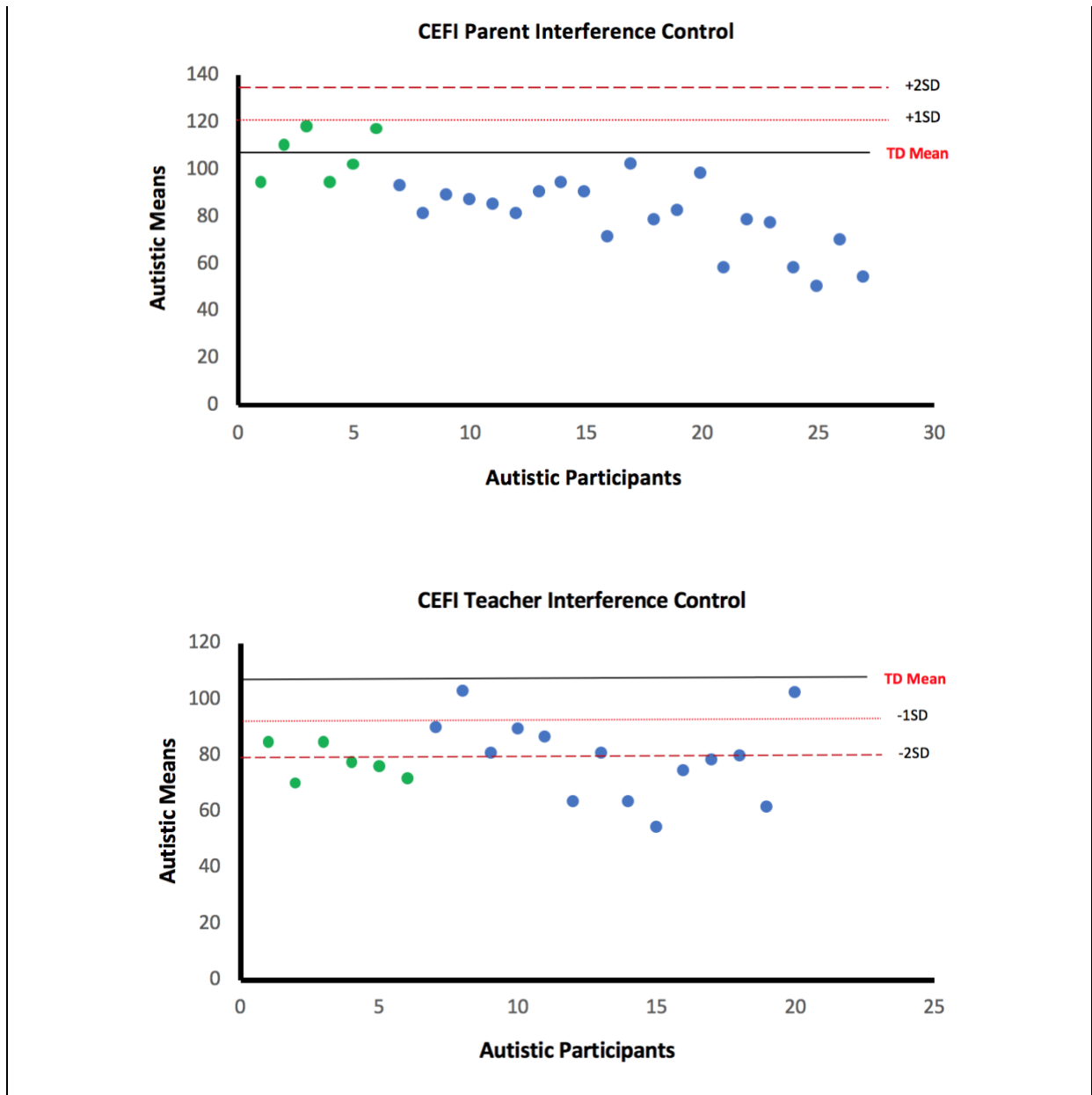


**Figure 3.0** Parent-reported sustained attention: A visualization of autistic performance relative to the typically developing mean

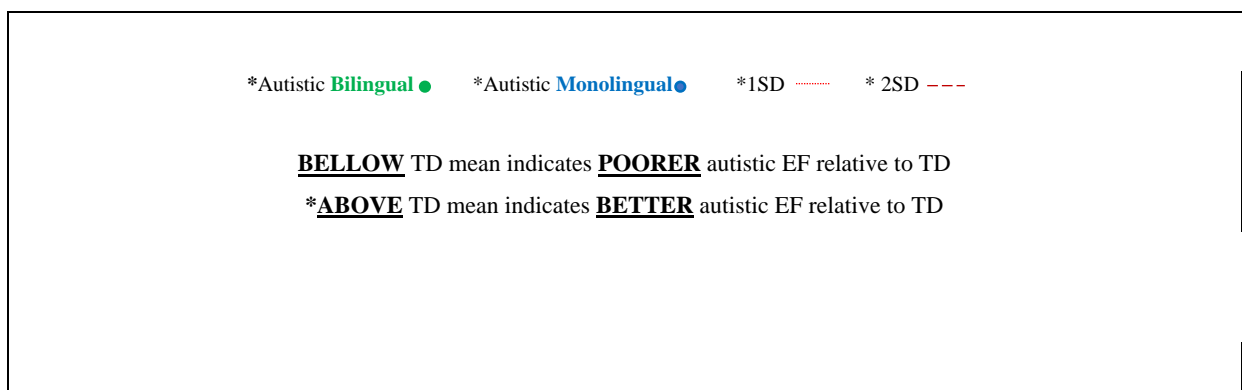
\*Autistic **Bilingual** ●    \*Autistic **Monolingual** ●    \*1SD - - -    \* 2SD - - -

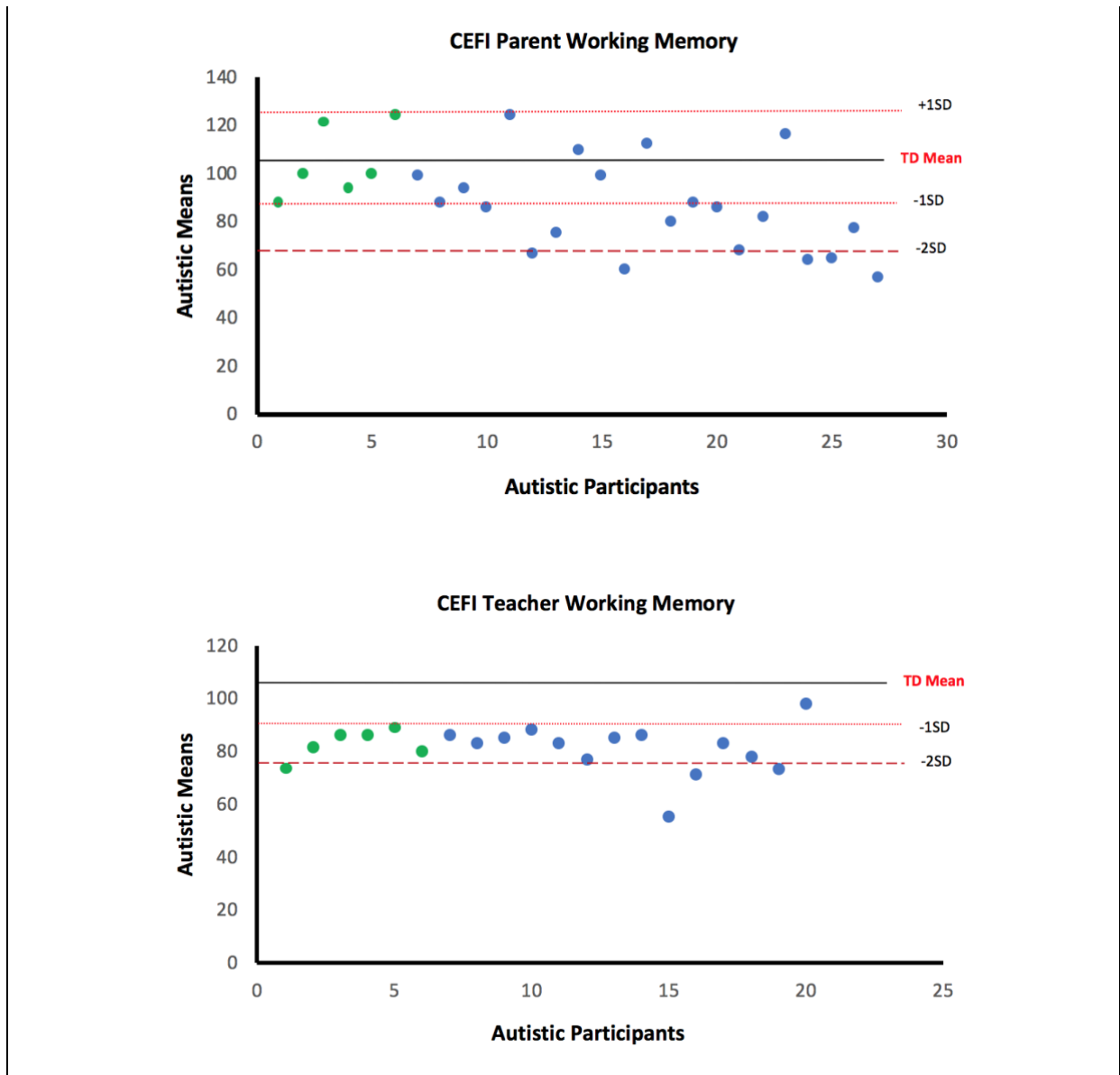
**BELLOW** TD mean indicates **POORER** autistic EF relative to TD

\***ABOVE** TD mean indicates **BETTER** autistic EF relative to TD



**Figure 3.1** Parent-reported interference control: A visualization of autistic performance relative to the typically developing mean





**Figure 3.2** Parent-reported working memory: A visualization of autistic performance relative to the typically developing mean

*Parent reports.* Figure 3.3 depicts the amount of variation across EF tasks obtained for each autistic participant at 1SD and 2 SD thresholds from the TD mean.

Very Impaired	>2SD <b>below</b> TD Mean indicates much poorer performance
Impaired	>1SD <b>below</b> TD Mean indicates poorer performance
Normal	Equivalent to TD Mean
Enhanced	>1SD <b>above</b> TD Mean indicates better performance
Very Enhanced	>2SD <b>above</b> TD Mean indicates much better performance

	CEFI Parent SA	CEFI Parent FS	CEFI Parent IC	CEFI Parent WM
A1	1.329	1.078	0.974	1.169
A2	-0.143	-0.81	-0.467	0.406
A3	-1.371	-1.681	-1.188	-1.121
A4	2.394	1.732	0.974	0.753
A5	0.265	-0.156	0.253	0.336
A6	-0.716	-0.156	-1.098	-1.329
A7	1.002	0.86	1.064	0.406
A8	0.593	2.531	2.146	1.169
A9	1.329	0.061	1.425	0.753
A10	1.739	0.933	1.605	1.308
A11	0.756	-0.81	1.786	-1.329
A12	1.493	1.296	2.146	2.627
A13	2.148	0.497	1.335	2.072
A14	-0.88	0.061	0.974	-0.357
A15	0.756	1.296	1.335	0.406
A16	3.13	3.621	3.048	3.113
A17	-0.143	-0.156	0.253	-0.496
A18	2.23	1.296	2.147	1.725
A19	1.984	2.749	2.056	1.169
A20	0.265	1.078	0.614	1.308
A21	2.394	2.967	4.22	2.558
A22	2.475	1.514	2.417	1.586
A23	0.511	1.296	2.507	-0.774
A24	2.475	2.749	4.22	2.835
A25	3.458	2.967	4.941	2.766
A26	2.885	1.514	3.138	1.933
A27	1.739	1.514	4.58	3.321

**Figure 3.3.**  $N = 27$ . Amount of variation across EF tasks obtained for each autistic participant (intra-individual variability) at 1SD threshold from the TD mean.

*Note.* CEFI Parent SA = CEFI Parent-Sustained Attention; CEFI Parent FS = CEFI Parent-Flexible Switching; CEFI Parent IC = CEFI Parent-Interference Control; CEFI Parent WM = CEFI Parent-Working Memory.

With respect to participants (rows A1 to A27), this analysis clearly shows: (a) no evidence of very enhanced autistic EF performance, (b) the majority of autistic EF performance is in the normal range, closely followed by very impaired performance, (c) every EF domain produces one instance of enhanced performance, with the exception of working memory which produces two instances, (d) only a handful of autistic children exhibit enhanced performance, namely, A3, A6, A11, (e) only one autistic child shows what looks like a spiky profile, namely, A11. Overall, this analysis does not support evidence of spiky EF profiles in autistic children.

With respect to EF outcome variables (columns CEFI Parent SA to CEFI Parent WM), this analysis clearly shows: (a) every EF outcome variable produces “very impaired” performance, (b) the majority of “very impaired” performance corresponded to interference control, (c) there are no instances of outcome variables producing “very enhanced” performance, (d) the only spiky profile from an EF outcome variable perspective corresponds to interference control and working memory, as both include multiple instances of “impaired” and “enhanced” performance.

*Teacher reports.* Figure 3.4 depicts the amount of variation across EF tasks obtained for each autistic participant at 1SD and 2 SD thresholds from the TD mean.

Very Impaired	>2SD below TD Mean indicates much poorer performance
Impaired	>1SD below TD Mean indicates poorer performance
Normal	Equivalent to TD Mean
Enhanced	>1SD above TD Mean indicates better performance
Very Enhanced	>2SD above TD Mean indicates much better performance

	CEFI Teacher SA	CEFI Teacher FS	CEFI Teacher IC	CEFI Teacher WM
A1	1.842	1.863	1.559	2.529
A2	2.316	1.319	2.541	1.915
A3	1.097	2.067	1.559	1.607
A4	1.571	1.863	2.017	1.607
A5	1.571	2.067	2.148	1.377
A6	1.91	1.183	2.41	2.068
A7	0.555	1.387	1.231	1.607
A8	0.487	2.067	0.379	1.838
A9	1.571	2.34	1.821	1.684
A10	1.3	1.183	1.231	1.454
A11	1.774	2.544	1.428	1.838
A12	3.062	3.088	2.934	2.299
A13	1.774	1.659	1.821	1.684
A14	2.791	3.496	2.934	1.607
A15	2.791	2.544	3.524	3.989
A16	2.045	2.135	2.214	2.76
A17	1.3	2.34	1.952	1.838
A18	2.113	2.135	2.188	2.222
A19	2.384	2.34	3.065	2.606
A20	1.029	1.863	0.379	0.686

**Figure 3.4**  $N = 20$ . Amount of variation across EF tasks obtained for each autistic participant (intra-individual variability)

*Note.* CEFI Teacher SA = CEFI Teacher-Sustained Attention; CEFI Teacher FS = CEFI Teacher-Flexible Switching; CEFI Teacher IC = CEFI Teacher-Interference Control; CEFI Teacher WM = CEFI Teacher-Working Memory.

With respect to participants (rows A1 to A20), this analysis clearly shows: (a) no evidence of ‘enhanced’, ‘very enhanced’, and ‘impaired’ autistic EF performance, (b) the majority of autistic EF performance is in the ‘normal’ range, followed by ‘very impaired’ performance. Overall, this analysis does not support evidence of spiky EF profiles in autistic children.

With respect to EF outcome variables (columns CEFI Teacher SA to CEFI Teacher WM), this analysis clearly shows: (a) every EF outcome variable produces ‘very impaired’ performance, (b) the majority of ‘very impaired’ performance corresponded to flexible switching, (c) there are no instances of outcome variables producing ‘enhanced’, ‘very enhanced’, and ‘impaired’ performance.

Figure 3.5 displays a side-by-side comparative view of MCSA findings based on directly-assessed and informant-report EF measures. While none of them represent spikes in EF, directly-assessed EF seems to reveal more strengths than parent-reported EF, which in turn, is more positive than teacher-reported EF.

Very Enhanced
Enhanced
Normal
Impaired
Very Impaired

	I-E	I-CRT	I-NCRT	WM-OB	WM-AS	SA-RT	SA-PS	FS-RTM	FS-SWCT
A1	-0.028	-1.176	-1.099	-0.395	-1.326	0.293	-0.526	-3.65	-3.543
A2	0.623	-1.733	-1.182	-0.711	-1.121	-0.67	0.899	0.35	0.683
A3	0.08	-0.891	-0.604	-1.31	-0.29	0.072	0.131	0.035	-1.691
A4	-0.571	-0.913	-1.115	-0.074	-1.741	-0.914	0.131	-0.5	-4.642
A5	-1.44	-0.205	-0.847	-0.711	-0.91	-1.565	-0.416	0.428	-0.021
A6	1.466	-1.831	-0.788	-0.074	0.115	-1.704	-1.074	-1.916	0.023
A7	-1.006	-0.711	-1.141	0.403	-1.53	-2.889	-0.745	0.081	-0.68
A8	-0.028	0.593	0.543	1.36	0.949	-0.624	0.131	0.6	0.584
A9	-2.527	-0.64	-1.834	-0.711	-1.121	-1.983	0.57	-3.29	0.847
A10	-0.137	-2.087	-1.962	-1.189	-0.706	-0.833	-0.745	-2.056	-4.078
A11	0.732	-2.198	-1.526	-1.668	-1.53	-4.039	1.118	0.1	-0.386
A12	-0.245	1.382	1.189	-1.831	-0.91	1.343	0.899	1.146	-2.241
A13	-2.962	-0.822	-2.272	-1.031	0.534	-0.31	0.57	-5.067	-4.457
A14	0.84	-0.043	0.351	-0.874	1.079	1.501	0.68	0.745	0.832
A15	0.188	-1.075	-0.847	-0.395	-1.121	0.374	1.118	0.448	0.779
A16	-0.354	-1.449	-1.526	-0.711	-0.981	0.27	0.131	0.735	-1.906
A17	-3.396	0.352	-0.872	0.403	-1.946	-2.145	0.57	-3.69	0.197
A18	-0.354	0.482	0.317	-1.831	-0.706	-0.473	0.789	-0.496	-29.342
A19	-0.463	-0.6	-0.797	-0.874	-0.085	-2.993	0.351	-1.687	-2.534
A20	-0.571	-0.236	-0.453	-0.553	-1.326	-0.357	0.131	0.178	0.475
A21	-0.897	0.997	0.577	-0.874	-0.706	-0.926	0.789	-1.531	0.252
A22	0.08	-0.65	-0.537	X	-0.91	-1.193	0.241	0.511	0.223
A23	X	X	X	X	-0.501	-1.53	-0.745	-2.131	0.73

Intra-individual variability:

*Directly-assessed EF*

	CEFI Parent SA	CEFI Parent FS	CEFI Parent IC	CEFI Parent WM
A1	1.329	1.078	0.974	1.169
A2	-0.143	-0.81	-0.465	0.406
A3	-1.371	-1.681	-1.188	-1.121
A4	2.394	1.732	0.974	0.753
A5	0.285	-0.156	0.253	0.336
A6	-0.716	-0.156	-1.096	-1.329
A7	1.002	0.86	1.064	0.406
A8	0.993	2.531	2.146	1.169
A9	1.329	0.061	1.425	0.753
A10	1.759	0.913	1.405	1.308
A11	0.756	-0.81	1.786	-1.319
A12	1.493	1.296	2.146	2.627
A13	2.148	0.497	1.355	2.072
A14	-0.88	0.061	0.974	-0.357
A15	0.756	1.296	1.355	0.406
A16	3.13	3.621	3.048	3.113
A17	-0.143	-0.156	0.253	-0.496
A18	2.23	1.296	2.147	1.725
A19	1.984	2.749	2.056	1.169
A20	0.265	1.078	0.614	1.308
A21	2.394	2.967	4.22	2.558
A22	2.475	1.514	2.417	1.586
A23	0.511	1.296	2.507	-0.774
A24	2.475	2.749	4.22	2.835
A25	3.458	2.967	4.941	2.766
A26	2.855	1.514	3.138	1.933
A27	1.759	1.514	4.58	3.321

Intra-individual variability:

*Parent-reported EF*

	CEFI Teacher SA	CEFI Teacher FS	CEFI Teacher IC	CEFI Teacher WM
A1	1.842	1.863	1.559	2.529
A2	2.316	1.319	2.541	1.915
A3	1.097	2.067	1.559	1.607
A4	1.571	1.863	2.017	1.607
A5	1.571	2.067	2.148	1.377
A6	1.91	1.183	2.41	2.068
A7	0.555	1.387	1.231	1.607
A8	0.487	2.067	0.379	1.838
A9	1.571	2.34	1.821	1.684
A10	1.3	1.183	1.231	1.454
A11	1.774	2.544	1.428	1.838
A12	3.062	3.088	2.934	2.299
A13	1.774	1.659	1.821	1.684
A14	2.791	3.496	2.934	1.607
A15	2.791	2.544	3.524	3.989
A16	2.045	2.135	2.214	2.76
A17	1.3	2.34	1.952	1.838
A18	2.113	2.135	2.188	2.222
A19	2.384	2.34	3.065	2.606
A20	1.029	1.863	0.379	0.686

Intra-individual variability:

*Teacher-reported EF*

**Figure 3.5** Intra-individual variability at a glance: A side-by-side MCSA comparison



### C. Investigating relationships: Directly-assessed EFs and autism features

The data were screened to ascertain whether they were normally distributed and log10 transformations were applied if the data were skewed. Pearson's correlation revealed no significant correlations between direct EF scores and the SCI and RRBs features. Table 11 provides a summary of results.

**Table 11.** Pearson correlations between autism features and direct EF outcomes.

	I-E	I-CRT	I-INCRT	WM-O8	WM-A8	SA-RT	SA-FS	FS-RTMT	FS-SWCT
SRS-2 T-Score	-.25	-.05	-.21	.29	.43	-.14	.13	-.04	.25
SCI T-Score	-.26	-.28	-.47	.00	.26	-.16	.04	-.23	.16
RRB T-Score	.18	-.45	-.40	.18	.03	.24	.08	-.53	.15

*Note.*  $N = 13$ ; I-E = Interference Control (Effect); I-CRT = Interference Control (Mean RT on Congruent Trials); I-INCRT = Interference Control (Mean RT on Incongruent Trials); WM-O8 = Working Memory (Mean Errors Set Size 8 Object Version); WM-A8 = Working Memory (Mean Errors Set Size 8 Abstract Version); SA-RT = Sustained Attention (Mean RT); SA-FS = Sustained Attention (Mean False Starts); FS-RTM = Flexible Switching (Mean RT on Mixed Trials); FS-SWCT = Flexible Switching (Switch Cost).

### D. Investigating relationships: Informant-report EFs and autism features

*Parent reports and autism features.* Potential relationships between parent reports and autism features were investigated. The p-value was Bonferroni adjusted to avoid Type 1 errors (0.05 / the number of analyses). The adjusted alpha level for significance is presented for each outcome variable. Table 12 summarizes relationship investigations and figures 3.6-4.0 visualize significant relationships ([Appendices: 1](#)).

**Table 12.** Correlations between autism features and parent-reported EF

	SRS-2 T-Score	SCI T-Score	RRB T-Score
CEFI Parent SA	-.541*	-.685**	-.586*
CEFI Parent FS	-.523*	-.631**	-.512*
CEFI Parent IC	-.560*	-.660**	-.704**
CEFI Parent WM	-.529*	-.665**	-.557*

Note. N = 16 . \*\* Correlation is significant at the 0.01 level (2-tailed), \*Correlation is significant at the 0.05 level (2-tailed).

The alpha level for significance was set at  $p < 0.018$ , using Bonferroni correction. A Pearson's  $r$  data analysis revealed a significant negative correlation between SCI and all four EF outcomes, namely : (a) sustained attention (poorer parent-reported sustained attention was associated with higher SCI atypicality scores), (b) flexible switching (poorer parent-reported flexible switching was associated with higher SCI atypicality scores), (c) interference control (poorer parent-reported interference control was associated with higher SCI atypicality scores), working memory (poorer parent-reported working memory was associated with higher SCI atypicality scores).

A significant negative correlation was revealed between RRB and interference control (poorer parent-reported interference control is associated with more RRBs), as well as RRB and sustained attention (poorer parent-reported sustained attention is associated with more RRBs). There was no significant correlation between RRB and flexible switching, working memory.

*Teacher reports and autism features.* Potential relationships between teacher reports and autism features were investigated. Only teacher reports with a consistency index of  $> 75$  (quality threshold) were included in the analysis. This led to a total of 20 participants whose data were analyzed in this section. Table 13 summarizes relationship investigations. The alpha level for significance was set at  $p < 0.018$ . Results indicate no correlation between SCI and all four EF outcomes. Only one EF outcome significantly correlated with the RRB T-Score and that was interference control (lower scores on teacher-reported interference control was associated with higher RRB score).

**Table 13.** Correlations between CEFI teacher ratings and autism features

	SRS-2 T-Score	SCI T-Score	RRB T-Score
CEFI Teacher SA	-.059	-.178	-.424
CEFI Teacher FS	.227	.147	-.268
CEFI Teacher IC	-.210	-.299	-.587**
CEFI Teacher WM	-.159	-.187	-.456*

Note. N = 20 . \*\* Correlation is significant at the 0.01 level (2-tailed), \*Correlation is significant at the 0.05 level (2-tailed)

## 7. Discussion

*Multiple case series findings.* Four key findings emerged from my MCSA investigation. First, the majority of autistic EF performance was revealed to be in the normal range, on both directly-assessed EF and informant-report measures of EF. Therefore, in contrast to group-level findings in Chapter 3 (using directly-assessed EF measures) and Chapter 4 (informant-report measures of EF) which reported autistic group deficits relative to TD peers on almost every EF outcome variable, MCSA insights (Chapter 5) reveal that the majority of autistic participants in our sample performed equivalently to TD peers. Therefore, to answer my first research question, MCSA revealed an insight that was concealed and could not be detected on a group-level as analyzed in Chapters 3 and 4.

Second, across all EF measures, only a handful of autistic children displayed spiky EF profiles, as per my threshold. Therefore, to answer my second research question, I did not find evidence of spiky EF profiles for the majority of autistic participants. The issue of threshold is a particularly important one. If my findings were analyzed through the threshold lens of studies like Maria Luz et al., 2014, they might be deemed as evidence of marked variability in EF performance.

Third, MCSA findings with teacher-reported EF indicates that the majority of autistic EF performance is in the ‘normal’ range, followed by ‘very impaired’ performance. This finding is consistent with group-level findings using teacher reports in Chapter 4; in contrast to parent-reports which revealed advantages for autistic bilinguals on every outcome measure, null findings were reported using teacher-reports. Also, it is possible that EF difficulties may not be very evident at home, but teachers (especially those with extensive experience), could be more perceptive of mild EF difficulties in a classroom-type setting, where children may need to be more focused and organized. Ultimately, the home and school environment can place different EF demands on children, with the latter being more demanding. This could explain the teachers’ frequent account of ‘very impaired’ EF performance, relative to parents’ accounts of EF.

Fourth, directly-assessed EF seems to reveal more strengths than parent-reported EF. This finding is consistent with studies that reported greater difficulties for autistic individuals on informant-report EF measures, rather than direct assessments of EF, in comparison with TD peers (Van Eylen et al., 2015; White et al., 2009).

*Executive function and autism features findings.* In the social communication domain, there were consistent relationships between parent-reported EFs and social communication.

Poorer parent-reported EFs, across all four domains, were associated with higher atypicality scores in social communication for autistic children. There were no relationships between social communication in autism and teacher-reported EFs nor directly-assessed EF outcomes. In the repetitive and restricted behaviors domain, two out of four parent-reported EFs - poorer parent-reported interference control and sustained attention - were associated with more clinically significant restricted and repetitive behaviors. Once again, there were no relationships between directly-assessed EFs and this feature. Using teacher reports, only one domain - poorer interference control - was associated with more pronounced restricted and repetitive behaviors.

Therefore, to answer my third and final research question, I found significant relationships between EF performance and diagnostic features of autism; the most consistent relationships were established via parent-reported EF. It is not clear why; given that it was teachers who filled out the SRS-2 forms, I would expect teacher-reported EFs to show more consistent relationships with autism features. As for directly-assessed EFs, my findings are consistent with other studies that didn't find any relationships between this type of EF measure and autism features (e.g., Ozonoff et al., 2004; Towgood et al., 2009).

A key limitation of this investigation is the lack of a comparison group. In the absence of a comparison group, it is difficult to determine whether the links established between parent-reported EF and autism features are specific to autism. Future research may address this by attempting to link parent-reported EF to clinical traits associated with autism in other groups of children, such as children with developmental conditions.

Overall, the findings of this MCSA support the view that autism is a spectrum condition that ranges from intact to impaired EF abilities. In fact, there is support that individual differences can explain the inconsistencies in EF findings both within (Towgood et al., 2009) and across (Guerts et al., 2009) studies on autism. While the present data confirm the presence of heterogenous EF profiles in autism, the source of this variability was not examined, and therefore, remains unknown.

The findings also emphasize the importance of administering multiple measures (e.g., direct and informant-report measures) in the assessment of EF in autism. In addition, Czermainski et al. (2014) provides support for combined methods (group and case series) in order to provide more consistent EF data in autism. By prioritizing the use of one method, often group methods, theoretically and clinically-relevant EF insights are likely to be missed. In fact, findings from both analyses (i.e., EFs in relation to autism features and MCSA)

suggest there is evidence that EF difficulties contribute to the manifestation of autism, but also, that the individual experience of autism shapes EF capabilities.

## Chapter 6: Discussion

### 1. Summary of findings

The current work presents four investigations, each contributing unique findings to the study of bilingualism in childhood autism, with a specific focus on investigating executive functions profiles. In my first investigation, using directly-observed experimental EF measures (Chapter 3), I found preliminary evidence that bilingualism might mitigate difficulties in the sustained attention domain for autistic children. Findings from this laboratory-type investigation, however, reflects EF abilities at one point in time and under specific circumstances. At best, this is a limited portrayal of EF, bilingualism, and autism. Therefore, I proceeded to ask, what is the impact of bilingualism on EF if the deployed assessment tools capture EF over a longer period of time and in daily, real-world types of situations?

To answer this question, I carried out a second investigation (Chapter 4) using informant-report measures that captures both parent and teacher views on children's EF abilities. Widespread EF advantages were detected for autistic bilinguals using a parent-reported EF measure, a finding that was not replicated using an identical report for teachers nor directly-assessed EF measures. Given these advantages, I then asked a follow-up question: what aspects of the bilingual experience predict parent-reported EF performance? I found that second language proficiency predicted parent-reported sustained attention whereas second language current exposure predicted parent-reported interference control. I also found that poorer parent-reported EF abilities were associated with more pronounced features of autism.

The results of these two analyses (Chapters 3 and 4) revealed some common ground. First, being autistic and bilingual did not result in any EF disadvantages, relative to monolingual autistic peers. Second, as a group, autistic children exhibited significantly poorer EF abilities relative to TD peers, on the majority of EF outcome variables. However, given the established heterogeneity between and within autistic children, I launched my third and final investigation (Chapter 5) to examine variability in my autistic EF data, using a multiple case series approach. A key finding of this chapter was that the individual experience of autism seemed to shape EF capabilities. To illustrate, in contrast

to group-level findings (Chapters 3 and 4) which classified autistic group performance as ‘impaired’, a multiple case series analysis showed that the majority of autistic participants performed equivalently to typically developing peers. This insight was concealed using group-level analyses only; the finding emphasizes the importance of combining analytic methods in EF investigations of autism to provide more consistent EF data.

While there was variability in the autistic group, the large majority of the sample did not have spiky EF profiles (i.e., one that has a mix of three performance levels). A key finding from the thesis as a whole, is that informant-report measures captured widespread bilingualism advantages but direct assessment captures intra-individual variability more successfully. The following sections discuss limitations of the project as a whole and implications of the aforementioned findings on aspects of theory, methods, and practice.

## **2. Limitations**

*Generalizability.* The large majority of the autistic children recruited into my study were school-aged and cognitively-abled. It is likely that the sample is not representative of the wider autistic community. Similarly, bilingual children in my sample were proficient in both their languages, and located in a dual-language environment. There is certainly not representative of all bilingual experiences. Replications with more cognitively, linguistically, and demographically-diverse samples are required. More importantly, future research should aim to include participants that represent different language switching contexts (i.e., single, dual, dense) for a robust test of the ACH.

*Confounders.* First, the data included in this work are cross-sectional, which restricts my ability to draw robust estimates of the effects of bilingualism on executive function outcomes. Robust longitudinal data are required to establish potential causal links at the interface of bilingualism and EF in childhood autism. In addition to an exploration of cognitive consequences of bilingualism (i.e., does bilingualism lead to EF differences?), the impact of executive function on language (i.e. reverse-causality (Baum & Titone, 2014; Cox et al., 2016); do differences in EF abilities lead some to become bilingual, while others not?), should be subject to investigation. Second, while I made every effort to maximize my sample size via nation-wide recruitment collaborations, my sample size was relatively limited. This restricted my ability to investigate a larger number of potentially relevant factors to performance. In the domain of bilingualism and EF, this includes the impact of exercise, musical training, active video gaming, to name a few (see Valian, 2015 for a focused review

on children, adolescents, and young adults). To illustrate, a study by Dye, Green and Bavelier (2009) revealed attentional benefits for child and adolescent active video game players on a computerized task.

*Measurement.* First, although carefully shortlisted with autistic participants in mind (e.g., computerized, explicit), a number of EF measures used in the current work lack validity and reliability information for use with autistic samples. This could have likely disadvantaged autistic groups on directly-assessed EF performance. Second, in an effort to reduce assessment demands on participants, I had to rely on a single measure of directly-assessed EF. Therefore, I was unable to evaluate the extent to which performance patterns are consistent, so that if an advantage is found for one task (e.g., my finding of a bilingual autistic advantage on the PVT measure of sustained attention) but not another, one can conclude that the advantage here is test specific, not EF-specific.

Third, the Arabic language measures utilized in this work were not available in the large majority of participants' local dialects. While all the children in my research were exposed to Modern Standard Arabic as part of their formal education, they often made responses in their local dialects, which sometimes had to be independently checked against Modern Standard Arabic equivalents in order to complete scoring. Thus, there is an urgent need for a variety of standardized dialect measures of Arabic to reliably assess language across a range of linguistic profiles. Fourth, information on children's language history and use such as language-switching tendencies and current language exposure were rated by parents; this could have introduced a potential bias in language history and use information.

Finally, treating bilingualism as a dichotomous variable (as I have done in my study) has been suggested to result in loss of power (Type II error) (one might miss a real effect), (Maxwell & Delaney, 1993). When bilingualism is treated as a continuous variable, measured on a continuum, this could lead to more consistent EF advantages (Luk & Bialystok, 2013; Suarez, Gollan, Heaton, Grant & Cherner, 2014; Yow and Li, 2015). Therefore, there are statistical and conceptual arguments in favor of approaching bilingualism as a continuous variable. I note, however, that this was not possible for my study, as 70% of autistic bilingual children and 82% of TD bilingual children had medium-high proficiency in both their languages. Therefore, treating bilingualism as a continuous variable was not appropriate for my investigation.

These limitations should be borne in mind in the discussion that follows. It is essential to recognize the need for a body of work combining information from multiple sources that



can inform theory, research design and practice in this field. Nonetheless, I will next consider the implications of my findings within academia and beyond.

### **3. Implications**

#### **A. Theoretical implications**

*Theories about autism.* With respect to cognitive theories of autism, findings from Chapters 3 and 4 only partially support the executive dysfunction theory of autism. Autistic participants had significantly poorer performance on both direct and informant-report measures of EF, relative to their TD peers – but only when analyzed as a group. When analyzed on an individual level (Chapter 5), the majority of individual assessment scores for individual autistic participants were within one standard deviation of the mean score of their TD peers. The latter finding, therefore, does not support the executive dysfunction theory, and rather, supports the view that it is the individual experience of autism that shapes EF capabilities. Therefore, the use of group-level analysis alone can lead to a dangerously misleading picture of autism both in a theoretical and clinical sense.

Furthermore, while I found evidence of a relationship between EF difficulties and the manifestation of autism, this was only apparent for parent-report measures of EF and autistic profiles. Moving forward, future investigations should aim to use a combination of analytic methods and measurements of EF to further our understanding of EF abilities in autistic children and how they relate to the manifestation of autism. It is worth noting that the current investigation is original and relevant in its focus on EFs in autistic children, as much previous research has focused on theory of mind instead. However, findings from this investigation can feed into research on theory of mind in autistic children. To illustrate, I found consistent relationships between parent-reported EFs and social communication. Poorer parent-reported EFs, across all four domains, were associated with higher atypicality scores in social communication for autistic children. If better EF facilitates better social communication, it is possible that the development of the ability to mentalize is supported through exposure to relevant social exchange (e.g., Hughes, 1998).

*Theories about bilingualism and EF.* The ACH model suggests that it is the bilingual's interactional context which modulates EF advantages. Dual language contexts, in particular, are proposed to be the most demanding for bilinguals. EFs most impacted by this context include interference control, sustained attention, and flexible switching. Being predominantly a dual-language switching environment, my research context was, therefore,

well-suited for this theoretical model. At the same time, it is less clear what this model would predict for my group of bilinguals. The large majority of bilinguals in my study are early bilinguals who have experience with frequently using and switching between Arabic and English, within a single context. They are also actively exposed to and engaged with different varieties of spoken Arabic. For these bilinguals, it's been suggested that a trade-off likely occurs between sustained attention (as well as inhibitory control) and disengagement of inhibition, which allows more flexible switching (Locke & Braver, 2008). This is because there is less of a need to stay focused on one language over a period of time and apply inhibition to one language while speaking the other, which allows for increased flexible switching. A likely implication for such a bilingual group (regardless of diagnostic status; autistic or typically-developing) is greater advantages on flexible switching tasks, as opposed to sustained attention and inhibitory control tasks. While my findings do not lend support to such an outcome, more research on autistic and typically-developing children with varying ages of first exposure to a second language and different language combinations, is needed to investigate any differential effects on EF.

While I have less to add to the already crowded and controversial literature on EF and bilingualism in general TD literature, the unique contributions of this thesis are with respect to autism. Using directly-assessed EF measures, I found no support for the ACH, given that only one outcome variable of sustained attention was positively impacted for bilingual autistic children. The lack of support for ACH was echoed using a teacher-reported EF measure. However, using a parent-report EF measure, I found widespread EF advantages. Whether my data lend support to the adaptive control hypothesis is, however, unclear. This is because I found an autistic bilingual advantage in EF areas hypothesized to be most impacted by a dual-language context (i.e., sustained attention, interference control, and flexible switching) but also, in an EF domain not hypothesized to be impacted by a dual-language context (i.e., working memory). It was for this exact purpose that working memory was specifically selected as a control in my study. This model would benefit from further testing, which would, in turn, provide supporting or refuting evidence for this theory, thereby also shedding light on the currently debated mechanisms by which cognitive control may be improved in bilinguals.

Since the adaptive control hypothesis was used to motivate the current study, it might be interesting to assess whether there were associations between performance on EF measures and more distributed dual language experience. In my study, all bilingual participants attended schools in which both Arabic and English were used (a dual-language

switching environment). This is typical of bilinguals in the UAE, and indicates little to no variation in linguistic environments across my bilingual sample. Therefore, I could not assess associations between EF performance and distributed language experience as I would then require additional samples from other language environments to make that comparison.

It may be that bilingualism positively impacts EF, including working memory, suggesting the ACH predictions are inaccurate. On another note, parental positive attitudes towards bilingualism and / or towards their children's language abilities might also be at interplay. I note that my data cannot resolve these possibilities and that further research is needed to disentangle these possibilities.

Another factor worth commenting on is the theoretical aspect of 'linguistic distance' (Wichmann et al., 2010). The linguistic distance between languages refers to the extent to which two languages are different, for example, in terms of semantics and / or phonology. Language pairings that are 'close' to one another present a greater overlap in semantic and lexical domains. This may exert higher demands on the executive system to exercise interference control (Tamar et al., 2011). For example, Catalan and Spanish, are relatively 'close' languages in terms of linguistic distance, whereas, Cantonese and English are 'distant'.

To illustrate, a recent study by Ramanujan (2019) investigated the relative linguistic distance in relation to cognitive control, in a sample of similar bilinguals groups with varying linguistic distances (e.g., low distance; Dutch-English, intermediate distance; Hindi-English, and high distance; Cantonese-English). The Dutch-English bilingual group displayed significantly greater involvement of interference control related to the two other bilingual groups. In the context of my study, it is possible that the large linguistic distance between English and Arabic could have masked interference control effects. It is worth noting that, within the limited evidence-base on linguistic distance, an opposite finding of linguistic distance has been reported across other investigations (e.g., Bialystok et al., 2005; Wierzbicki, 2014). Therefore, future well-powered investigations with varying language pairings (varying linguistic distances) are warranted.

The next section outlines methodological implications which should be taken into consideration for future testing of the ACH. The can also apply to the brain training hypothesis, which just like ACH, should be subjected to further empirical testing. This is because both theories make suggestions regarding the mechanism by which bilingualism could modulate EF abilities.

## **B. Methodological implications**

A few key methodological insights emerged from my combined investigations. First, there is an emphasis on careful selection of tasks through piloting measures in advance to inform the main EF investigation. Tasks must be considered in relation to a guiding theory, including – ideally – multiple tasks to triangulate underlying ability more robustly. This includes a task which is not related to the guiding theory, as a control. While I was unable to experiment with two EF tasks per domain of interest (my pilot insights revealed that children did not tolerate this well), I successfully attempted to shortlist tasks that: capture EF domains relevant to the ACH model, had reported psychometric properties in the TD literature, were computerized to present reduced verbal and social task demands for children with autism, generally had low working memory demands, and were previously used in the study of ED in autism.

One task, however, might need to be re-considered for future investigations – the Simon Task. It has been argued that paradigms like Flanker Task demand distinct inhibitory abilities from those of the Simon Task. To illustrate, incongruency on a task like the Flanker Task (which I eliminated in the pilot phase, based on pilot insights) is driven by conflict between a congruent stimulus in the center / focus of attention and an incongruent stimulus in the edge / border of attention. In contrast, incongruency in the Simon task is driven by a lack of alignment / configuration between the spatial position of the stimulus and the spatial position of the respective key to be pressed. Basically, there is a single stimulus at all times that is in the center / focus of attention, irrespective of whether it is congruent or incongruent. Unlike the Flanker Task (which I shortlisted for piloting but later eliminated from my main EF investigation as per pilot insights with children), the Simon Task (my second shortlisted task) requires participants to exercise response inhibition of a prepotent response whenever the stimulus (colored squares) is incongruent to the respective key (Poarch & Van Hell, 2012). While some argue that the Simon Task is a popular task of interference control; spatial interference, I recognize the presence and interplay of response inhibition as a limitation. As mentioned earlier, this particular EF domain does not quite replicate the experience of being bilingual, and therefore, is less likely to confer any advantages. It is possible, therefore, that the use of this task may have masked any potential benefits in interference control for the bilinguals in my study.

Second, the analyzing the ‘right’ EF outcome variables is a key methodological insight from this work. One should not hastily proceed to analyze all outcome variables

produced by a particular task as this can further complicate and potentially mislead our understanding of EF abilities in a particular population. To illustrate further, the sustained attention task I deployed in my study (i.e., the PVT) results in three key outcome variables, namely, ‘mean false starts’, ‘mean number of lapses’, and ‘mean RT’. However, in my research, I only carried forward ‘mean false starts’ and ‘mean RTs’ to analyses, thus excluding ‘mean number of lapses’ from my investigation of sustained attention in autistic children.

This is because, during data collection, I observed that some autistic participants voluntarily allowed some trials to lapse, despite being prompted to press the space bar as soon as the visual stimulus appeared on the screen. This led to longer reaction times and lapses, which could be interpreted as poor sustained attention. Rather, this behavior was associated with a desire to satisfy ‘completion’. In other words, they just really enjoyed the sight of an empty circle filling up in a bright color all the way to completion (plenty of smiles and hand-flapping once the circle was 100% red!). Therefore, extrapolating only relevant outcome variables from administered tasks is key for autistic EF investigations.

Third, a key methodological insight from the thesis as a whole, is that informant-report measures captured widespread bilingualism advantages (i.e., parent reports of EF) but direct assessment captures intra-individual variability more successfully. In the literature, there is evidence that each type of measure underlies different abilities. A review by study by Samyn et al. (2015) suggests that direct and rating measures of EF capture different kinds of information, with direct measures reflecting a child’s abilities at one point in time under specific circumstances capturing “state-like” data, and questionnaires reflecting a child’s specific, daily capacities across a wider time span, capturing “trait-like” data (Samyn et al., 2015). For example, informant-report measures avoid a common methodological limitation experienced with direct EF assessments as they assess EF abilities in natural environments, thus, boosting ecological validity. Another component supporting its ecological validity is the fact that informant-report measures, unlike direct EF assessments, are carried out by people who interact with the individual on a daily basis in natural settings.

To summarize, one type of measure (informant-report) is not necessarily ‘better’ than another (direct assessments); each offers distinctive types of information regarding EF abilities, and both contribute to our understanding of EF profiles in autistic children. A key direction for future research is the inclusion of multidimensional EF measures in the study of EF in autism.

Fourth, to mitigate the effects of small sample sizes, future research might consider the creation of a composite EF score, by collapsing measures with conceptually related EF variables into a single score, thus strengthening reliability (e.g., Antoniou et al., 2016). On another note, it is important to draw attention to statistical approaches that can prove particularly beneficial for autism research. Studies at the interface of bilingualism and autism either report a bilingual autistic advantage (i.e., hypothesis) or no advantage / no disadvantage (i.e., null hypothesis), with the latter reflecting the majority of findings. The null hypothesis, therefore, demonstrates that bilingual autistic children do not differ from their monolingual autistic peers (i.e., while they are not better across linguistic and cognitive domains, they are also not worse off). This finding is of clinical importance, carrying implications for interventions and family dynamics. Therefore, it is important to acknowledge statistical approaches that can offer positive evidence in favor of the null hypothesis – such as Bayesian statistics. Rather than simply not finding evidence to reject the null hypothesis, this approach can actually provide evidence that the null hypothesis is true.

Fifth, age-related inclusion criteria must be thoughtfully considered in relation to EF development. While my investigations included children only (early to late childhood; 5-12 years), it must be acknowledged that there are distinct adjustments in EF development across childhood, which make EF performance comparisons (e.g., a 5-year-old versus a 10-year-old) difficult. Future EF investigations, especially ones that can access larger sample sizes, should aim to recruit children with similar EF developmental patterns.

### **C. Implications for practice**

Concerning the language domain, my findings are in line with previous research suggesting that, to date, empirical evidence does not support limiting language exposure to one language only for autistic children living in bilingual / multilingual families or societies. Not only can autistic children become proficient bilinguals and function in two languages, the finding of no negative impact of bilingualism on their EF abilities is a robust finding, revealed by all measures of EF. In fact, preliminary evidence from the few studies at this interface, mine included, even suggest there could be potential EF advantage for autistic bilinguals. This finding has practical implications for interventions with autistic children. For instance, based on the evidence, one can argue that parents should be encouraged to use the language they feel more comfortable with to interact with their children.

Developing language abilities in autistic children from bilingual and multilingual family language backgrounds is key for the development of ethnic identities and increased social communication both within and outside the home (Kremer-Sadlik, 2005; Wharton et al., 2000). Therefore, it is important that autistic children access all those opportunities and not be denied the language familiarity they need to be a part of their family and community. On that note, researchers and practitioners should make every effort to educate families on the evidence-base surrounding bilingualism and EF in childhood autism (for example, in my study, there was enhanced performance for autistic bilinguals on parent-reported EFs and a directly-assessed EF task). Doing so, helps counteract unfounded notions and expectations surrounding bilingualism in autism. Therefore, even with small to medium effect sizes, the observed bilingual advantages can be clinically meaningful for this population, with impact on interventions and family dynamics. Does this mean that bilingualism is for everyone? Most likely, it is not. Ultimately, it is a combination of quality evidence-based findings, children's abilities and preferences, and family preferences and dynamics – that should inform language-based decisions in autistic children.

Finally, the diversification of autism research samples (one of the key contributions of my work) should be a top priority for future research agenda, as currently, the vast majority of autism research focuses on White (often middle class) families. As a result, autism services and supports tend to be designed for this segment of the population which leaves out the majority of families worldwide – families of autistic children from a variety of cultural and ethnic backgrounds.

#### **D. Implications for education**

Discrepancies from findings with parent and teacher-EF reports could potentially be attributed, in part, to different requirements and expectations of the home and school environment. That means each EF environment is unique. Schools, in particular, often promote EF-demanding, fast-paced environments with exposure to varied cognitive-boosting activities – that might support the experience of bilingualism. Furthermore, in my study, I found that second language proficiency predicted parent-reported sustained attention whereas second language current exposure predicted parent-reported interference control – both these markers of bilingualism can be largely developed through language experiences at school. Moreover, being able to function in two or more languages has undeniable benefits for educational and learning opportunities – which autistic children should have equal access to.

#### **4. Conclusion**

Challenging preconceived notions and misconceptions surrounding bilingualism and autism, the current work provides evidence of no EF disadvantage to being autistic and bilingual. This is a robust finding across all EF investigations. On the contrary, findings suggest that being bilingual might result in some EF advantages. Deploying a range of EF measures and thinking creatively about analysis (i.e., individual differences and group differences) allows for capturing consistent and unique data, potentially revealing a range of unique abilities within autistic profiles. Such data can lead to robust theoretically and clinically-relevant insights. Given that every autistic child is unique, and can be shaped by a number of nurturing life experiences (just like typically developing children), there is evidence to suggest that bilingualism is one such candidate experience.



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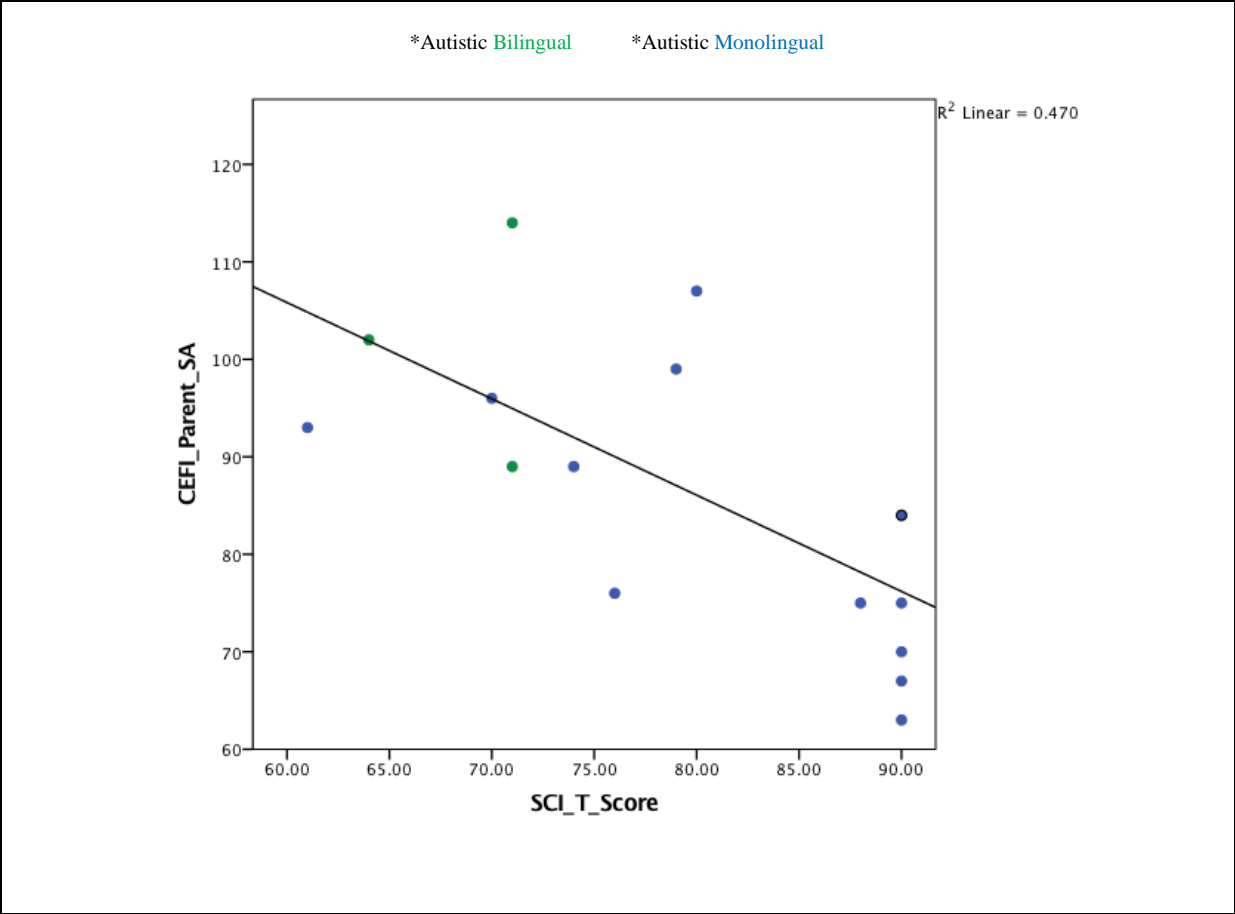


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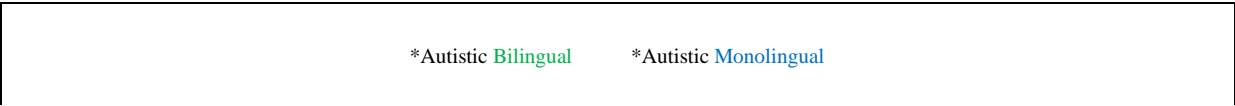
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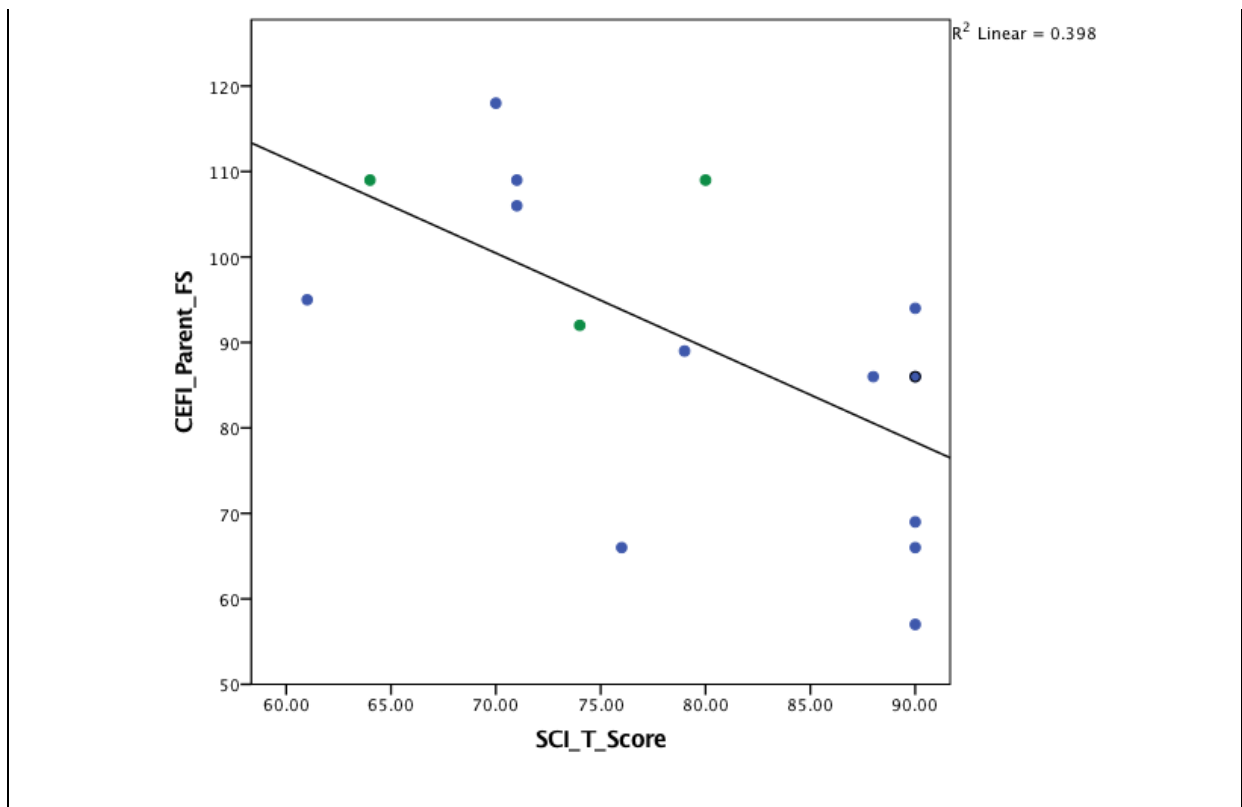
# Appendices

## 1. Relationships between autism features and parent, teacher reports of EF

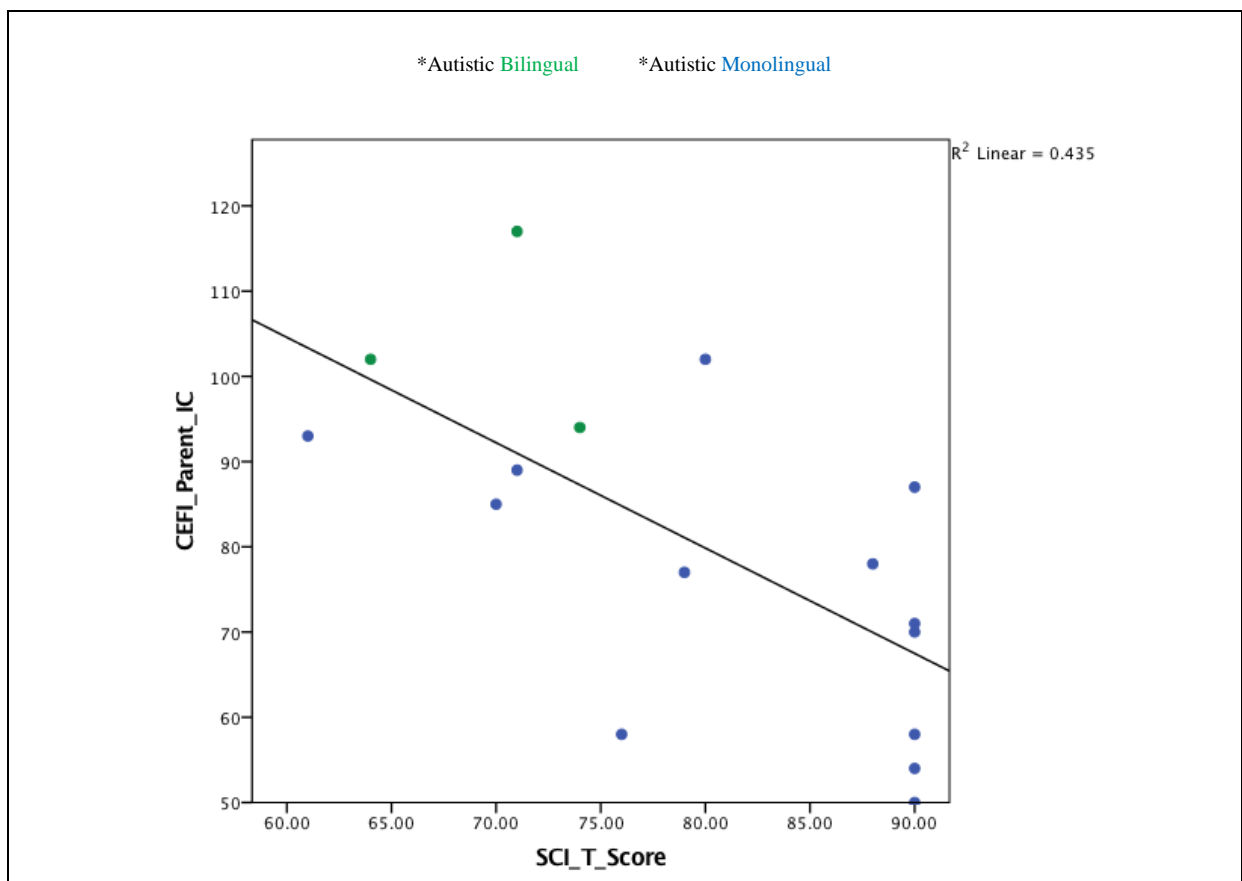


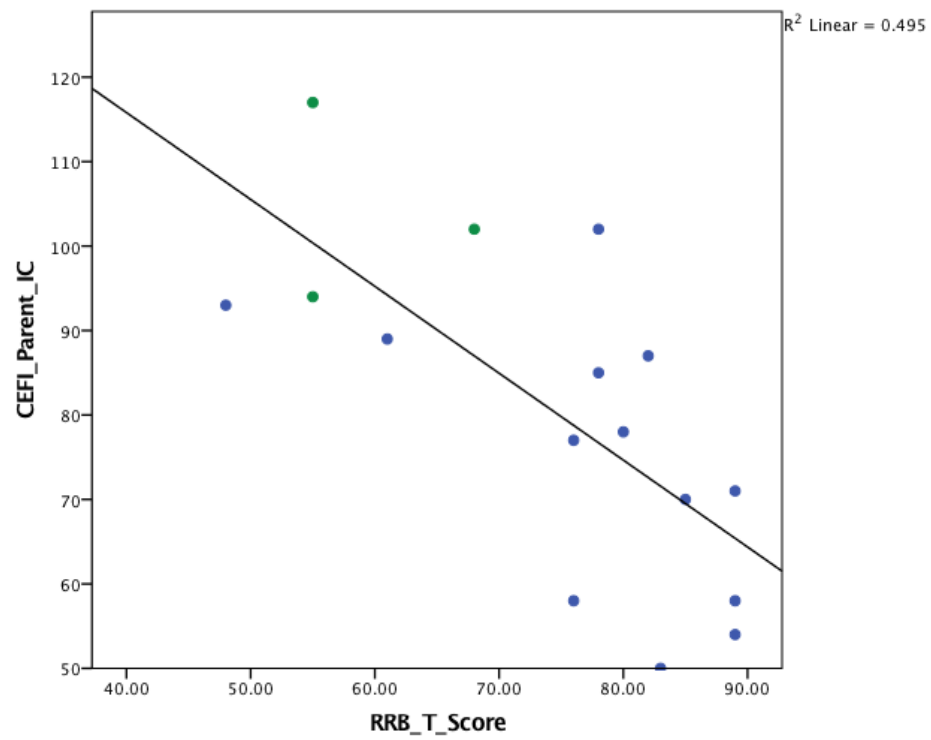
**Figure 3.6** Relationship between parent-reported sustained attention and social communication in autism.





**Figure 3.7** Relationship between parent-reported flexible switching and social communication in autism.

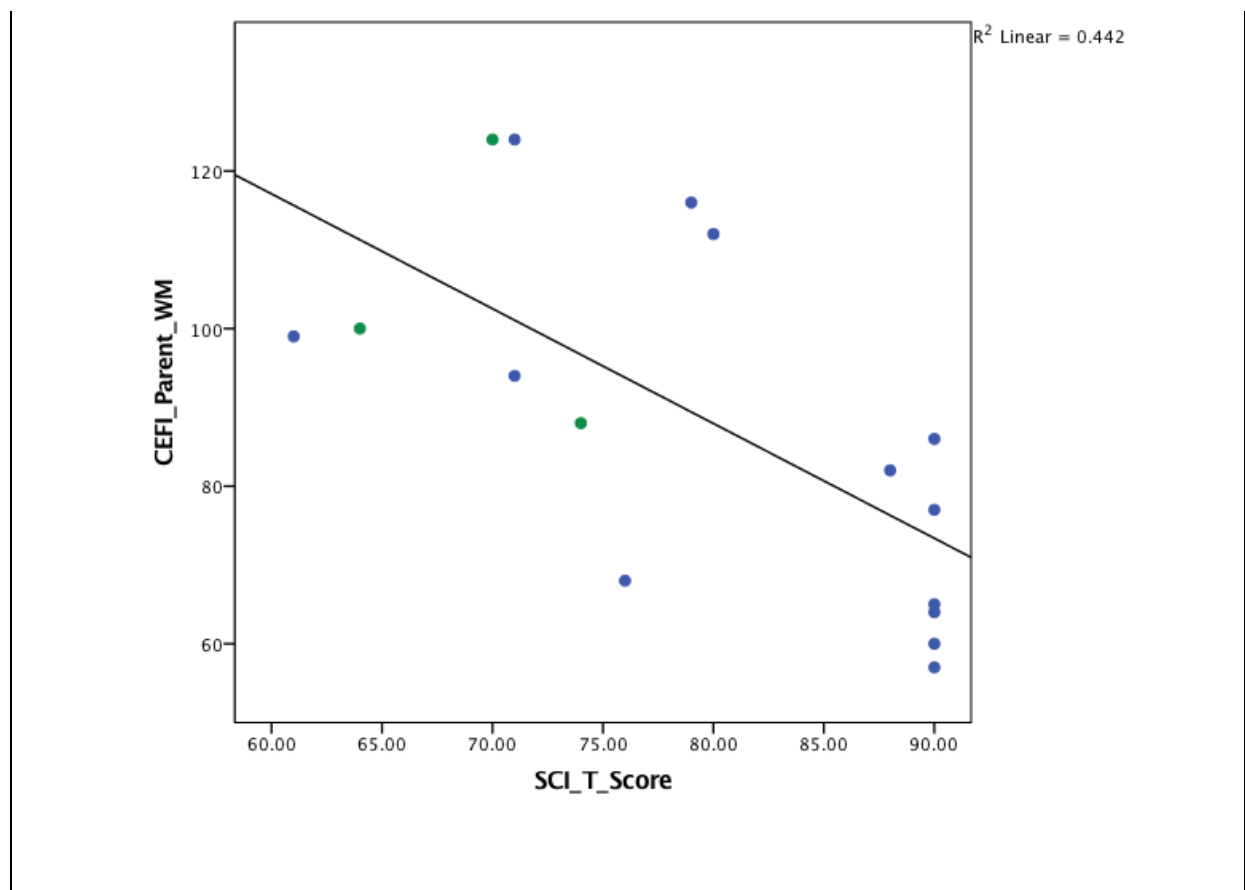




**Figure 3.8** Relationship between parent-reported interference control and restricted and repetitive behaviors in autism.

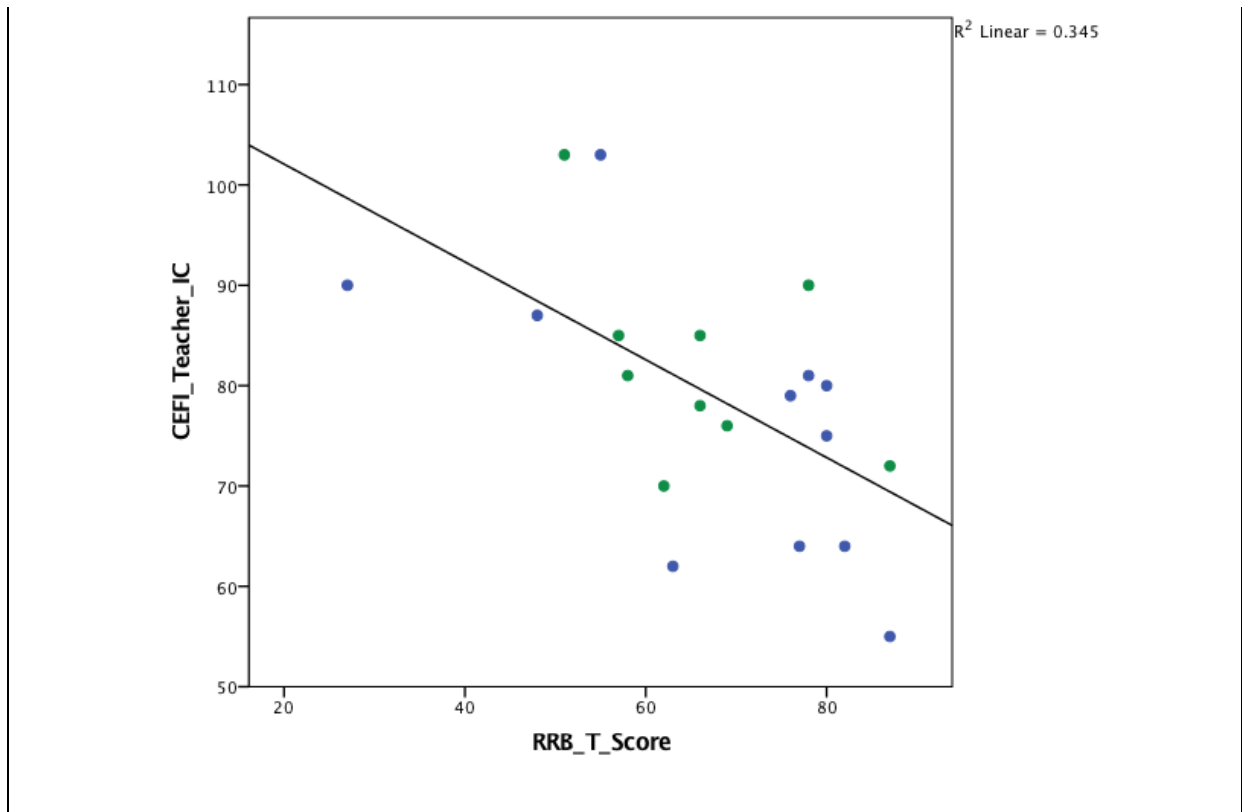
\*Autistic Bilingual

\*Autistic Monolingual



**Figure 3.9.** Relationship between parent-reported working memory and social communication in autism.

\*Autistic Bilingual      \*Autistic Monolingual



**Figure 4.0.** Relationship between teacher-reported interference control and restricted and repetitive behaviors in autism.